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American Journal of Science

FEBRUARY 1949

THE FLOOR OF THE SHENANDOAH VALLEY[1]

PHILIP B. KING

ABSTRACT. The floor of the Shenandoah Valley near Elkton, Va., is commonly supposed to be the dissected surface of the Valley Floor or Harrisburg peneplain. Actually, the principal element of the floor is a series of gravel-capped benches, formed in Pleistocene time during alternating periods of erosion and deposition, and rising step-like toward the bordering mountains away from the flood plain of the South Fork of the Shenandoah River. Unconformably beneath the gravels is residual clay, resulting from the decay of the bedrock of Cambrian and Ordovician limestone, dolomite, and shale. The clay is thickest on the southeast side of the valley, where it attains 200 feet. It probably formed during a single epoch in the Tertiary, under mild and humid climatic conditions, toward the close of a period of peneplanation—that is, near the time of completion of the Valley Floor peneplain. At one locality a small body of ancient gravel, probably of Tertiary age, lies stratigraphically between the residual clay and the Pleistocene gravels, and is unconformable with each. The Valley Floor peneplain is believed by some authors to have been formed in late Tertiary time, but the sequence of events implied by the geological materials of the Elkton area suggests that it is considerably older.

INTRODUCTION

A GREAT deal that has been written on the geomorphology of the Appalachian area has to do with land forms and surfaces, and much less has been written on the geological materials of which these surfaces are composed. This paper deals with the geological materials which compose the land forms of one area in the Appalachians, that near the town of Elkton in the Shenandoah Valley of northern Virginia. Although many details are uncertain, it is the writer's belief that the Cenozoic history was more complex than has generally been supposed, and probably different from what one would conclude from a study of the land forms alone.

In 1940 and 1941, the writer and John Rodgers, now of Yale University, mapped geologically a belt of country 20 miles along the northwest foothills of the Blue Ridge and the

[1] Published by permission of the Director, U. S. Geological Survey.

southeast edge of the Shenandoah Valley in the vicinity of Elkton, Va. The investigation was a part of the wartime strategic minerals program of the U. S. Geological Survey, and the purpose was a search for reserves of manganese ore. The investigation included study of stratigraphy and structure of the bedrock formations, of manganese-bearing residuum which overlies some of the bedrock, and of superficial deposits that overlie the residuum and bedrock. During the same period the U. S. Bureau of Mines prospected two tracts in the area by means of drill holes and shafts, and their results were studied geologically by the writer. The investigation was therefore focused on surface and near-surface geological materials, and provided an exceptional opportunity to correlate these materials with the land forms.

The economic aspects of the investigation in the Elkton area were set forth in a strategic minerals bulletin (King, 1943), and the general geology has been described in a manuscript that has recently been submitted to the Geological Survey for publication (King, 1947). This paper is a summary of one chapter in the latter manuscript.

GENERAL GEOGRAPHY AND GEOLOGY

The Elkton area lies in Page and Rockingham Counties, Va. The town of Elkton is 20 miles south of Luray and 18 miles east of Harrisonburg. The area is drained by the South Fork of the Shenandoah River, which follows the axis of a gently sloping valley—the southeastern branch of the Shenandoah Valley—from 4 to 7 miles wide, which stands at an altitude of 800 to 1,000 feet (map, figure 1). The valley is bordered on the southeast by the Blue Ridge and its fringe of foothills, whose summits rise to altitudes of nearly 4,000 feet. It is bordered on the northwest by the narrow hogback ridges of Massanutten Mountain, the highest of which reach an altitude of 3,300 feet.

The bedrock of the area consists of formations of pre-Cambrian, Cambrian, Ordovician, and Silurian age, the oldest lying to the southeast and the youngest to the northwest. Table 1, below, shows the general succession insofar as it bears on the discussion that follows:

TABLE 1

Generalized Section of Bedrock Units in Elkton Areas, Virginia.

Age	Formation	Thickness (feet)	Lithologic character	Topographic expression
Silurian	Sandstone and quartzite	500	Sandstone and quartzite	Ridge crests of Massanutten Mountain
Ordovician	Martinsburg shale	2,800	Shale and sandy shale	Northwest slope of Shenandoah Valley
	Limestone	200	Thin-bedded limestone	Axis of Shenandoah Valley; in places overlain by thin residuum
	Beekmantown dolomite	3,000	Thick-bedded dolomite	
Cambrian	Conococheague limestone	2,000	Thick-bedded, argillaceous and sandy limestone	
	Elbrook dolomite	3,000	Thin-bedded dolomite	
	Waynesboro formation	1,700	Red and brown shale; thin limestone beds	Southeast slope of Shenandoah Valley; generally overlain by thick residuum
	Tomstown dolomite	1,000	Dolomite, argillaceous dolomite, some shale	
	Antietam quartzite Harpers shale Weverton quartzite Loudoun formation	2,900	White, thick-bedded quartzite above, underlain by quartzite, siltstone, and shale	Foothills of Blue Ridge; hogbacks, dip slopes, strike ridges; much talus
Pre-Cambrian	Catoctin greenstone and underlying sediments Injection complex		Massive volcanic and plutonic rocks	Slopes and summits of Blue Ridge

The Blue Ridge is formed of massive pre-Cambrian volcanic and plutonic rocks, and its summits, standing at altitudes of 3,000 feet or more, are nearly flat or gently rolling in many places. These flat areas have been interpreted as peneplain remnants (Stose, 1919, pp. 37-38; and other authors) and have been correlated partly or wholly with the Schooley pene-

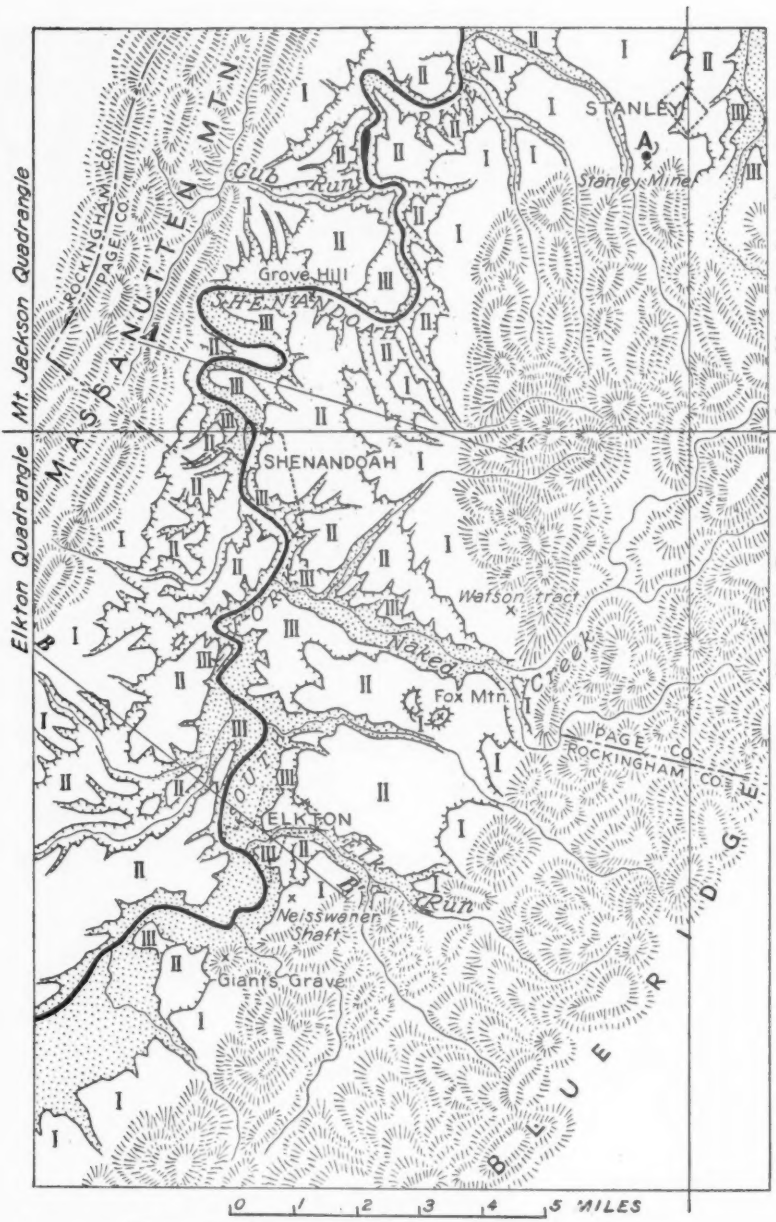
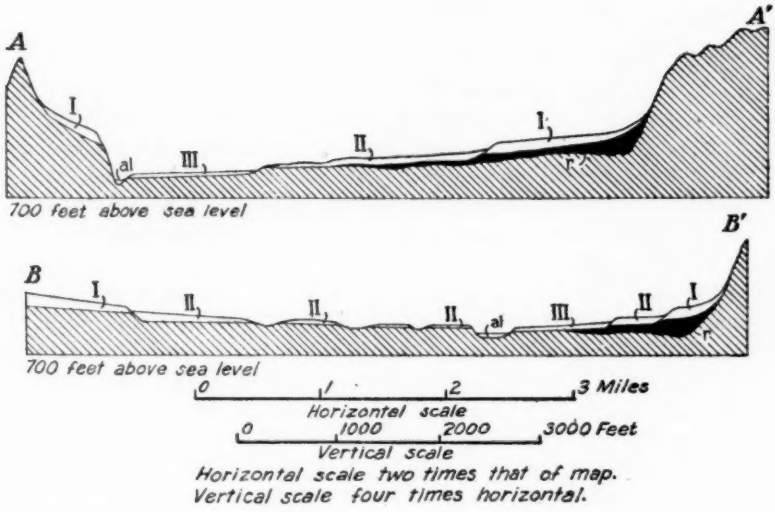
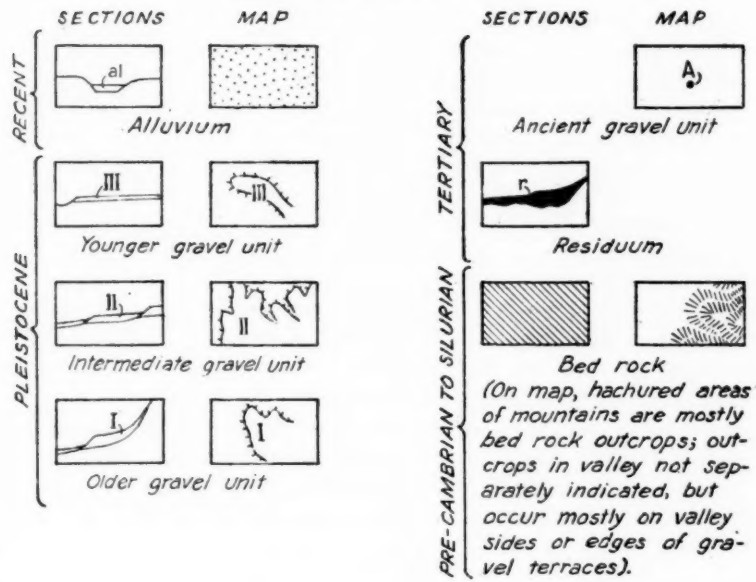


Figure 1. Map and sections of Elkton area, Virginia,



EXPLANATION



showing Cenozoic deposits, and localities mentioned in text.

plain. The crests of Massanutten Mountain have likewise been interpreted as controlled by a former high-level peneplain (Keith, 1894, p. 391; Spencer, 1897), perhaps the Schooley. Remnants of ancient erosion surfaces may well exist on the Blue Ridge, but it is uncertain how many are represented, as the flat summits stand at divergent heights in different places. If a surface once existed in the Massanutten Mountain area, it is now poorly preserved, for the mountain consists of ridges with knife-edged tops, without any flat summit areas. Below the Schooley level in parts of northern Virginia another surface, the Intermediate or Weverton peneplain, has been reported (Keith, 1894, p. 238; Stose, 1919, pp. 38-39). No evidence for this was seen in the Elkton area; the slopes intervening between the summit of the Blue Ridge and the floor of the Shenandoah Valley are steep and irregular, and there is no systematic arrangement of the foothill crests.

The area here called the "floor of the Shenandoah Valley" derives its name from the terms "valley floor" and "valley floor peneplain" which were used in older reports. Actually, it appears level only by contrast with the mountains which rise on either side. In detail it is a complex of rock-cut surfaces, of residuum, and of gravel deposits, standing at various heights above the flood plains of the present streams, and sloping gently from the bases of the Blue Ridge and Massanutten Mountain toward the axial stream in the center—the South Fork of the Shenandoah River (sections, fig. 1). Relief on the floor exceeds 500 feet in places. The surface and near-surface materials of the valley floor are indicated in table 2, below, and are described in more detail later in this paper. Rock outcrops occupy relatively small areas, chiefly in the stream valleys. By far the greater part of the surface is formed by the older, intermediate, and younger gravel units (table 2). The principal surface on the floor of the Shenandoah Valley has been interpreted as the Valley Floor, Harrisburg, or Shenandoah peneplain (Keith, 1894, pp. 374-376; Stose, 1919, pp. 39-40; Wright, 1934, pp. 28-31), a concept that will be examined at the conclusion of this paper.

RESIDUUM

Character.—The residuum of the area results from the decay of the rocks of the valley floor, and consists of insoluble

TABLE 2

Surface and Near-Surface Materials on Floor of Shenandoah Valley, Elkton Area.

Age		Name of unit	Description	Topographic relations
Quaternary	Recent	Alluvium	Gravel, sand, and clay.	Flood plains of South Fork of Shenandoah River and major tributaries.
	Pleistocene	Younger gravel unit	Thin sheet of gravel; same composition as older gravel unit.	Terraces near river, and 50-75 feet above it.
		Intermediate gravel unit	Thin sheet of gravel; same composition as older gravel unit.	Broad plains and benches on intermediate slopes of valley floor.
		Older gravel unit	Gravels, composed of pebbles and boulders, mainly of quartzite; gravel sheet thickens into coalesced alluvial fans at bases of mountains.	Narrow benches at bases of mountains, 300 to 700 feet above river.
Tertiary		Ancient gravel unit	Sand and gravel, in eroded basins in residuum, overlain unconformably by older gravel unit; mineralized.	Small areas only.
		Residuum	Clay, waxy or silty; chaotic structure; mineralized by iron and manganese oxides.	Mainly on Tomstown and Waynesboro formations, beneath older gravel unit and near foot of Blue Ridge; thin residuum on younger formations to northwest.
Unweathered bedrock of Cambrian and Ordovician limestones, dolomites, and shales.				

material, principally waxy or silty clay, which remains after the solution of limestone and dolomite, or after kaolinization of sericite in shale (King, 1943, pp. 21-26). Mixed with the clay are sand and silt, a residue of originally sandy or silty rocks, and chert, originally in the form of concretions in the carbonate rocks. Some of the clay also contains nodules, plates, and impregnations of iron and manganese oxides, which were introduced into the clay after its formation by processes of mineralization and replacement (Stose and others, 1919,

pp. 44-45; King, 1943, pp. 32-35). These oxides form the iron and manganese ores of the area, and have been mined where concentrated in bodies of sufficient size. Much of the clay has a chaotic structure, resulting from collapse, compaction, and creep that took place during the reduction in volume of the original rock.

Thickness.—The residuum is thickest over the Tomstown dolomite and Waynesboro formation on the southeast margin of the valley, and is thin or even wanting over the younger carbonate formations along the axis of the valley (sections on fig. 1).

The volume of the residuum overlying the Tomstown and Waynesboro formations is indicated mainly by test holes and mine workings. Test holes put down by the U. S. Bureau of Mines on the Watson tract, 5 miles northeast of Elkton, showed a thickness of residuum of the Tomstown dolomite of 100 to 150 feet (section A, fig. 2). Test holes south of Giants Grave, 3 miles south-southwest of Elkton, showed a thickness of residuum of the Tomstown dolomite of 50 to 100 feet. The Neisswaner shaft, a mile south of Elkton, showed a thickness of residuum of the Waynesboro formation of nearly 200 feet (Hewett, 1916, pp. 61-67) (section B, fig. 2). The deepest residuum penetrated on the Watson tract extends down to the altitude of nearby Naked Creek, along which residuum is also exposed, and that in the Neisswaner shaft extends below the altitude of the nearby South Fork of the Shenandoah River.

The residuum of the younger carbonate formations farther out in the Shenandoah Valley is thinner. Thin bodies of residuum were noted above the unweathered Elbrook and Beekmantown dolomites in some outcrops, and somewhat thicker bodies were noted above the Conococheague limestone (fig. 3). In some places residuum is wanting, as along the east side of the South Fork of the Shenandoah River at Elkton, where unweathered Elbrook dolomite is overlain directly by gravels. The base of the residuum of the younger carbonate formations also seems to be higher with respect to the present drainage than that of the Tomstown and Waynesboro formations. Near Elkton unweathered Elbrook dolomite and Conococheague limestone are 50 feet or more above river level, whereas unweathered Waynesboro formation lies below river level in the Neisswaner shaft not far to the southeast. North of the town

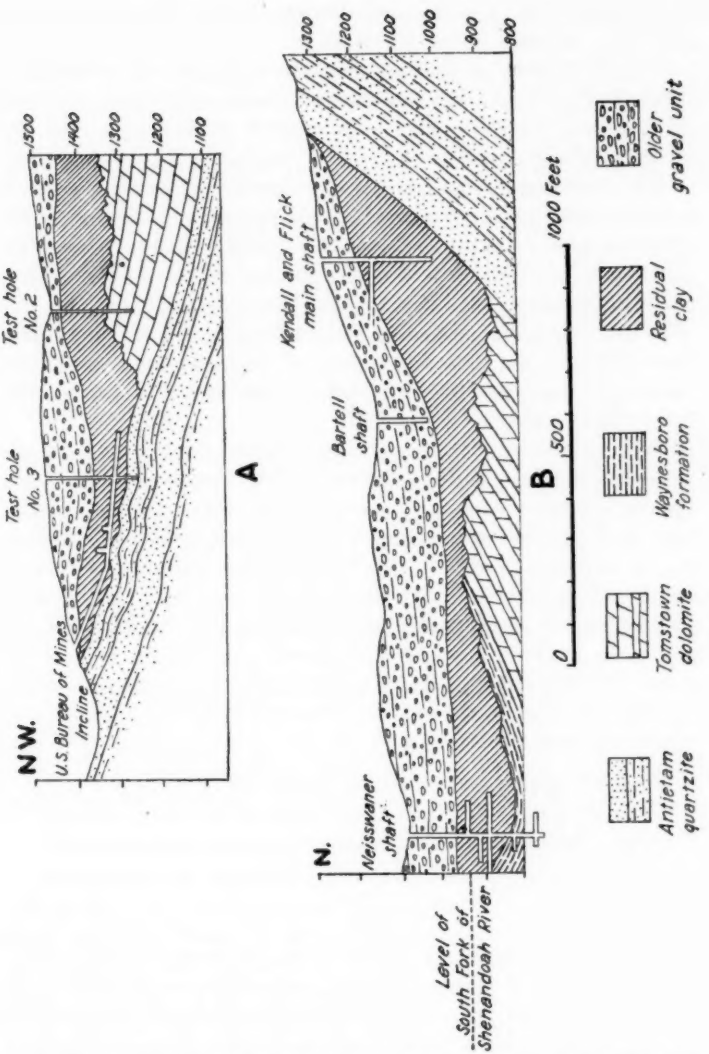


Figure 2. Sections showing inferred relations of gravel and residuum to bed rock along northwest foot of Blue Ridge. A. — On Watson tract, 5 miles northeast of Elkton. B. — Near manganese mines a mile southeast of Elkton. Section A based on Bureau of Mines drill holes and underground workings put down in 1941. Section B based on published records (Hewett, 1916).

of Shenandoah, unweathered Beekmantown dolomite extends 100 feet or more above river level.

The Martinsburg shale, northwest of the axis of the Shenandoah Valley, seems to have given rise to only small amounts of residuum, and ledges of unweathered shale extend 300 feet or more above river level.

The residuum is unconformable beneath the older, intermediate, and younger gravel units, this relation being visible in many mine workings, and in road and railroad cuts (figs. 2, 3, and 4). Open cuts of mines in residuum of the Tomstown and Waynesboro formations show coarse, cobbly or bouldery older gravels lying on the eroded surface of the residuum, and truncating the contorted structure of the residuum. The gravel contains fragments of iron and manganese oxides reworked from the residuum.

Origin.—Residuum is not being actively accumulated at the present time. Rock outcrops on valley slopes cut below the uplands of the valley floor show little or no surface accumulation of clay. Clay is no doubt being released today by weathering of carbonate rocks on the valley slopes, but under present conditions it is being carried away by erosion. The thickest accumulations of clay are beneath the upland surfaces of the valley floor, where removal by erosion would be even more active at the present time. Moreover, the clays are mineralized by iron and manganese oxides, yet many such deposits, according to Hewett (1916, p. 44)

> "are situated near the top or along the slope of isolated hills or spurs, so that since dissection of the peneplain began they have received very little of the surface drainage or ground water that might contain manganese in solution."

The unconformable relation of the residuum to the older, intermediate, and younger gravel units indicates that the collapse, compaction and creep accompanying the clay formation, and the subsequent mineralization of the clay, took place before these gravels were laid down.[2] It is therefore probable that the main accumulation of residuum took place before the

[2] In a previous report (King, 1948, p. 22) it was implied that accumulation of residuum took place during each erosion period which preceded each epoch of gravel deposition. This is now regarded as unlikely.

deposition of the oldest gravels, and it may well have been accomplished in a single epoch.

The thickest masses of residuum are those on the Tomstown dolomite and Waynesboro formation. In part this is because formations lie farthest from the axis of the valley. Their residuum would therefore be less subject to attack by later erosion than would residuum of the younger formations. However, the base of their residuum in many places extends below the level of modern drainage, and lower than the base of the residuum of formations near the axis of the valley. Very deep circulation of ground water evidently took place, for surface drainage at the time of formation of the residuum stood at a higher level than modern drainage. Along this belt of outcrop, circulating water may have been guided by the impervious beds of the Antietam quartzite which underlies the Tomstown. Similar observations and interpretations have been made by Rodgers in Bumpass Cove, Tennessee (1948, p. 15 and fig. 3).

The residuum may have accumulated in a single epoch. During this epoch, the climate may have been warmer and more humid than the present one (Hewett, 1916, pp. 46-47). Accumulation took place when the present upland areas of the valley floor lay near the grade of the streams which drained them, and when erosion was not sufficiently active to remove the residuum as it formed. In other words, conditions on the valley floor had then reached a state of peneplanation. This epoch no doubt corresponds to the time of completion of the Valley Floor or Harrisburg peneplain. The age of the Valley Floor peneplain will be considered at the conclusion of this paper.

DEPOSITS BETWEEN RESIDUUM AND OLDER GRAVEL UNIT

Lying stratigraphically between the residuum and the older gravel unit are small remnants of other deposits. Because of their position they are seldom revealed in natural exposures, but they have been uncovered in mine workings and other artificial openings. Only one remnant of such deposits was observed in the Elkton area, here termed the ancient gravel unit, but they occur widely in the southern Appalachians, as indicated below.

Ancient gravel unit at Stanley Mine.—The single observed occurrence of the ancient gravels lies in the north part of the Elkton area, in the open cut of the Stanley Mine, which is a mile southwest of Stanley at an altitude of 1,350 feet. The

deposit fills a steep-sided, eroded basin in clay residual from the Tomstown dolomite, and is overlain unconformably by coarse deposits of the older gravel unit (fig. 4). The ancient deposit consists of cross-bedded red sand, in which deeply weathered, rounded pebbles of sandstone and quartzite are

Figure 3. Section showing relation of residuum to Conococheague limestone and younger gravel unit in cut on Norfolk and Western Railway, three-fourths mile southeast of railroad station in Shenandoah.

Figure 4. Section showing relation of ancient gravel unit to residuum and older gravel unit in southern open cut of Stanley Mine, 1 mile southwest of Stanley. Section is schematic, being made by combining several outcrops within the cut.

embedded. Like the underlying clay, the deposit contains nodules and masses of manganese oxides that have impregnated or replaced the original sandy sediment. The overlying older gravel unit at this locality contains pieces of manganese oxides reworked from the residuum and from the ancient gravels, indicating that at least a part of the manganese mineralization of these units took place between the time of deposition of the ancient and older gravel units.

Related deposits in other areas. — Mineralized, ancient gravels occur at the same stratigraphic position elsewhere in Virginia. Manganese-bearing pebbly sand and clay have been encountered and mined at the Kennedy Mine, Augusta County (Stose and others, 1919, pp. 103-107), and at the Midvale Mine, Rockbridge County (Hewett, 1916, p. 60), southwest of the Elkton area.

At other localities in the southern Appalachians deposits at the same stratigraphic position have been worked for bauxite. One of these occurs southwest of Greenville, Augusta County, Va., and others are found in Tennessee, Georgia, and Alabama. These were intensively studied by Geological Survey field parties under the direction of Josiah Bridge during the recent war, but most of the results have not been published. One of the deposits, near Elizabethton, Tenn., was studied by the writer and his colleagues (King and others, 1944, pp. 45, 210-213), and according to Bridge resembles those elsewhere. It lies on the valley-floor upland, and consists of a mass of kaolinitic clay with a central core of bauxite, and forms a steep-sided pocket in residuum of the underlying carbonate bedrock. Lying in the kaolin are contorted lenses of lignite. The lignite at Elizabethton, and at most other deposits, has failed to yield identifiable plant remains, but according to Bridge, plant remains collected in clay and bauxite deposits in sink holes on the valley-floor surface near Anniston, Ala., and Cedartown, Ga., have been identified by R. W. Brown as of Midway (Paleocene) age.

Age of deposits between residuum and older gravel unit.— At least two types of deposits occur between the residuum and the older gravel unit—mineralized sand and gravel, and kaolinitic bauxitic lignite-bearing clay. The origin of the deposits was diverse, and perhaps also their age, for the epoch between the time of formation of the residuum and the time of deposition of the older gravels was probably a long one. As indicated

by plant remains in Georgia and Alabama, some are early Tertiary. The age of those in Virginia is unknown, but they seem most probably to have been laid down during some part of the Tertiary period.

GRAVEL DEPOSITS

Wide areas of the floor of the Shenandoah Valley are covered by gravel deposits, laid down on several surfaces that stand above the level of modern drainage. Each deposit lies on a terrace or bench, and is separated from the next by a low scarp (map and sections, fig. 1). The relations between the deposits are typically displayed southeast of Elkton, on the ridge next southwest of Elk Run, where three benches are present between the South Fork of the Shenandoah River and the adjacent mountains (section BB′, fig. 1). In some other parts of the area the differentiation is less evident; the units may merge without a distinct intervening scarp, or isolated gravel patches can be assigned only doubtfully to one unit or another. In general, however, a tripartite division of the gravels seems possible, and the units are herein referred to as the older, intermediate, and younger gravel units.

Older gravel unit.—The older gravel unit, which is the highest above the present streams, forms a series of remnant benches that fringe the northwest base of the foothills of the Blue Ridge and the southeast foot of Massanutten Mountain. In addition, two gravel-capped remnants, probably of the older gravels, stand above the plain of the intermediate gravel unit well out in the Shenandoah Valley at Fox Mountain (map, fig. 1).

The upper surface of the older gravels is probably depositional. At the outer edges of the remnants the surface stands at altitudes of 1,100 to 1,200 feet, and slopes gently toward the axis of the valley. On the mountainward sides the surface rises rapidly to heights as great as 1,500 feet and assumes the form of a piedmont alluvial slope. On the Massanutten Mountain side, where Cub Run enters the Shenandoah Valley, a fine alluvial fan is developed in the older gravels.

The deposits of the older gravel unit are probably thickest beneath the piedmont alluvial slope at the edge of the mountains. On the Watson tract, close to the mountains, test holes of the U. S. Bureau of Mines show thicknesses as great as 140

feet (section A, fig. 2). Similar thicknesses are present in the shafts of the mines a mile southeast of Elkton (Hewett, 1916, pp. 61-67) (section B, fig. 2), and in Bureau of Mines test holes south of Giants Grave, 3 miles south-southwest of Elkton. Near Stanley, in the northeast part of the area, thicknesses of 50 to 175 feet of gravel are reported by Cady (1936, pp. 80-81).

The older gravel deposit consists of pebbles, cobbles, and boulders, lying in rough layers in a sandy clay matrix. Most of the fragments are quartzite, derived on the Blue Ridge side of the Shenandoah Valley from the Antietam quartzite and other Lower Cambrian formations of the foothill belt, and on the Massanutten Mountain side from sandstone of Silurian age. Most of the quartzite fragments are rounded, indicating a certain amount of transportation, but near the apices of some of the former alluvial fans are angular blocks up to 4 feet in diameter. The older gravels do not show any evidence of mineralization, deep weathering, or other marks of extreme antiquity. Most of the component boulders are fresh and strong, although in a few places they have disintegrated to such an extent that they can be crushed into sand.

Intermediate gravel unit.—The intermediate gravel unit covers the most extensive area of the three (map, fig. 1). In places, these gravels form broad plains, as in the tract northeast of Elkton, between Elk Run and Naked Creek. As with the older gravel unit, the surface of the intermediate gravels rises toward the margins of the Shenandoah Valley and away from its axis, but alluvial fans are not developed on the mountainward sides. The surface of the intermediate gravels stands at an altitude of about 1,000 feet in the south part of the Elkton area, but descends northeastward, in harmony with the gradient of the South Fork of the Shenandoah River, to an altitude of less than 900 feet in the north part.

The intermediate gravel unit, like the older gravel unit, is composed largely of rounded quartzite fragments of various sizes. Some of the fragments may have been derived directly from erosion of the parent ledges in the mountains, others were derived no doubt from reworking of fragments in the older gravels.

A significant area of the intermediate gravels lies north of Grove Hill and northwest of the South Fork of the Shenandoah

River. Along the county road east of State Highway 12 and immediately north of the river, the intermediate gravels contain large numbers of fragments readily identifiable as having been derived from the Antietam quartzite and other Lower Cambrian formations of the foothills of the Blue Ridge. In this vicinity and throughout the whole north part of the Elkton area, the South Fork of the Shenandoah River flows in a series of entrenched meanders (map, fig. 1). The locality north of Grove Hill lies northwest of the river on the inside of one of the meander loops. The presence here of fragments derived from the Blue Ridge on the opposite side of the river to the southeast suggests that the meanders did not come into existence until after the deposition of the intermediate gravels. The meanders may have formed toward the close of the period during which the intermediate gravels were deposited.

Younger gravel unit.—The younger gravel unit lies on benches between the intermediate gravels and the present flood plain of the South Fork of the Shenandoah River (map, fig. 1). The tops of the benches are 50 to 75 feet above river level. Most of the benches are small—the largest occupying an area of about one square mile—and many lie within the loops of the entrenched meanders of the river. The whole thickness of the gravels may be observed along the edges of the benches and is less than 25 feet. The younger gravels have nearly the same composition as that of the two preceding gravel units.

Origin and age of gravel deposits.—The gravel deposits of the Elkton area are part of an extensive system of gravels that covers much of the southeastern part of the Shenandoah Valley from the headwaters of the Shenandoah River northeastward beyond Luray (Butts, 1933, geologic map), yet little has been written on them, and the few interpretations that have been made regarding them are open to question. Stose (1919, p. 36) and Wright (1934, p. 31) mention the gravels briefly and suggest that the older were laid down during the closing stages of the formation of the Harrisburg or Valley Floor peneplain, and that the younger were river terrace deposits.

The older, intermediate, and younger gravel deposits seem to be closely related in origin. The cycle of which each succeeding deposit is a part began with dissection of the bed rock or residuum of the valley floor, and eventual reduction of part of the floor to a graded surface. During later stages of the

cycle, deposits accumulated on the surface previously cut. Each cycle closed with renewed cutting by the streams to new and lower levels.

The main causes of these cycles were probably fluctuations in climate. During the initial stages of a cycle, streams were capable of transporting out of the region all the material supplied to them, because of adequate volume and because erosion was not active on the adjacent mountains. During such times, the climate was probably humid, thus permitting adequate stream flow, and protection of mountain areas from erosion by the growth of vegetation. The climate during such times was probably at least as humid as at present, and perhaps more humid.

During the later stages of a cycle, streams were incapable of removing all the material supplied to them, because of inadequate volume and because of vigorous erosion on the adjoining mountains. Butts (1940, p. 509) has interpreted the times of gravel deposition as times of greatly increased rainfall, but this view is hardly tenable. Probably the climate was dry, thus reducing the volume of stream flow and the cover of vegetation on the mountains, and exposing the mountains to attack by the forces of erosion. The climate was undoubtedly different from the present and probably was much drier, for quartzite wash is not being delivered from the mountains to the valley floor today in any such quantities as it was during the time of gravel deposition.

The successive gravel deposits are so closely related in origin that they are probably not far apart in age. Moreover, none of them exhibit marks of great antiquity, such as cementation, mineralization, or deep weathering. Very probably all the gravel deposits are of Quaternary age,[3] and were formed during the Pleistocene epoch. The fluctuations in climate herein suggested probably correspond to the fluctuations known to have taken place during the Pleistocene, the humid periods corresponding to glacial stages, and the dry periods to interglacial stages.

ALLUVIUM

Alluvium occupies the flood plains of the modern streams in the Shenandoah Valley, but it covers relatively small areas

[3] In a previous report (King, 1943, pp. 18 and 27) the older gravels are classed as of Tertiary or Quaternary age, and the intermediate and younger gravels as of Quaternary age. There seems to be no justification for this distinction.

(map, fig. 1). From the town of Shenandoah northward the flood plain along the South Fork of the Shenandoah River is very narrow, and in places the river is enclosed by rock walls on either side. South of Shenandoah, as in the vicinity of Elkton, the alluvial areas along the river are more extensive, and in places exceed a mile in width. Here, many of the tributary streams also lie in alluvial bottoms.

The thickness of the alluvium varies. North of Shenandoah, where the South Fork of the Shenandoah River is enclosed for long distances by bedrock, riffles occur here and there in the river itself, and suggest that bedrock lies directly beneath the channel. In the broad alluvial area southwest of Elkton, bedrock is exposed in places in the channel, but at the Stonewall plant of Merck & Co., not far southeast of the river and 2 miles southwest of Elkton, water wells encounter 31, 38, 57, and 124 feet of unconsolidated deposits above the bedrock.[4] The broad alluvial flat in the vicinity of Elkton is therefore underlain by variable thicknesses of unconsolidated deposits. Some of the thicker masses may represent buried river channels; others may be the filling of sink holes.

RELATIONS BETWEEN FEATURES OF VALLEY FLOOR

The descriptions just given indicate that the floor of the Shenandoah Valley includes a number of incompatible features, formed under contrasting conditions, and probably widely separated in time. In view of these circumstances, the earlier and simpler conception of the valley floor as a part of the Valley Floor or Harrisburg peneplain tends to disappear. Actually, the widest tracts of valley floor in the Elkton area are the depositional surface of the intermediate gravels, formed at a time by no means as remote as that assumed for the Valley Floor peneplain. The entrenched meanders of the South Fork of the Shenandoah River, commonly assumed to date from the time of formation of the Valley Floor peneplain, likewise seem to have been formed during the closing stages of the period in which the intermediate gravels were deposited. As the residuum that accumulated on the Valley Floor peneplain is now everywhere eroded and overlain unconformably by gravel deposits, it is unlikely that any remnants of the former

[4] Records of Virginia Geological Survey, through courtesy of W. M. McGill, State Geologist, September, 1947.

peneplain surface are still present in the Elkton area. The surface features of the valley are entirely those that were established during the periods of gravel deposition and later.

Both Keith (1894, pp. 374-376) and Fenneman (1938, pp. 247-248) have noted a marked increase in the gradient of the Shenandoah Valley above Front Royal, as compared with its lower or northern section. This gradient is stated to be incompatible with the slope assumed for the Valley Floor peneplain at the time of its completion, and hence to be suggestive of subsequent warping or uplift. Insofar as the Shenandoah Valley in the vicinity of the Elkton area is concerned, the gradients discussed by Keith and Fenneman are not those of the Valley Floor peneplain, but of the gravel deposits. These gradients are in harmony with the regimen of Pleistocene and modern streams, but they are out of harmony with conditions, as they are assumed to have existed, at the time of the formation of the Valley Floor peneplain and its accompanying residuum. A change in gradient has clearly taken place, either by warping or by some other means.

The history of the valley floor before the deposition of the gravels evidently occupied a long period of geologic time, even though the land surface itself was not notably lowered by erosion. First, residuum accumulated slowly as a result of rock weathering, probably in a warm and moist climate, under conditions of peneplanation. Afterwards, deposits such as the ancient gravels were laid down locally on the surface. In Georgia and Alabama, fossil plants in deposits on the valley floor surface indicate that these deposits are of early Tertiary age. The deposits in Virginia may be as ancient, but their age has not been proved. After the deposition of the ancient deposits, both their surface and that of the residuum was eroded before the older gravels were deposited. If the older gravels are Pleistocene, the events which preceded their deposition would seem to require a considerable span of Tertiary time.

According to widely accepted theories of Appalachian evolution, the shaping of the present land forms was accomplished in later Tertiary time. Johnson (1931, pp. 14-21) considers that the Schooley peneplain was not completed until middle Tertiary, and the Harrisburg peneplain not until late Tertiary. Stose, who believes that the Schooley was formed much earlier, now (1940, pp. 461-476) suggests that it was not

materially dissected until the Miocene, which would result in assigning about the same date to the completion of the Harrisburg surface. This is not the place to consider the elaborate structure of deduction on which conclusions of these and other authors have been based. The writer can only state that the dates thus assigned for the completion of the Valley Floor or Harrisburg peneplain do not seem sufficiently ancient to account for all the events which appear to have taken place on the valley floor, as indicated by the geological materials observed in the Elkton area.

ACKNOWLEDGMENTS

In this study of the Cenozoic history of the Elkton area, the writer is particularly indebted to his colleague, John Rodgers, who saw in the field many of the features herein described, and who subsequently was a helpful critic of the writer's manuscripts. The writer wishes to express his gratitude to Prof. R. F. Flint for reading and criticizing an early draft of the manuscript of this paper, and for encouraging its preparation for publication. Great aid has also been received from Josiah Bridge, who made helpful suggestions while the writer was working out the Cenozoic sequence of the Elkton area, and who supplied valuable supplemental information based on bauxite investigations of the U. S. Geological Survey. The discovery and proper interpretation of the ancient gravels at the Stanley Mine was worked out in the field jointly by H. D. Miser and the writer. W. M. McGill, State Geologist, has kindly supplied records of water wells from the files of the Virginia Geological Survey.

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U. S. Geological Survey
Gatlinburg, Tennessee

LATE PLEISTOCENE AND RECENT CHANGES OF SEA LEVEL ALONG THE COAST OF SANTA BARBARA COUNTY, CALIFORNIA

J. E. UPSON

ABSTRACT. At the mouths of three coastal valleys of Santa Barbara County, California—the Santa Ynez and Santa Maria Valleys and the Goleta Basin—evidence from well borings indicates that Pleistocene streams carved valleys graded to sea level which at that time was at least 200 feet and probably a maximum of about 300 feet below present level. These valleys, now filled with alluvium whose surface is graded about to present sea level, were cut below a marine terrace having a peak shore line about 100 feet above present sea level. Fossils in deposits on the wave-cut bench of the terrace suggest that the terrace is upper Pleistocene in age. The prealluvial valleys are believed to have been cut as a result of lowered sea level accompanying the maximum glaciation of the Wisconsin stage; and the terrace may have been formed during the immediately preceding interglacial stage. The suballuvial valley bottoms are about the same distance below present sea level; and the subsequent relative rise of the sea (about 300 feet) is considered to be a eustatic rise. The previous relative decline (maximum of about 400 feet) is considered to be almost wholly eustatic, although a small part of it may have been due to rise of the land.

Comparison of the longitudinal profile of the suballuvial valley of the Santa Ynez River on the one hand and that of the nearly contiguous Arguello submarine canyon on the other indicates that the two profiles were formed in distinctly different episodes. The formation of the submarine canyon (by whatever process) is thought to be older, and is considered pre-Wisconsin.

Introduction

Purpose of the paper

DROWNED valleys now more or less wholly filled with alluvium have been described at several places along the California coast. The most outstanding example is San Francisco Bay, but many similar though less conspicuous features have been noted elsewhere. Ellis and Lee (1919) early described alluvium-filled valleys along the streams in San Diego County; and Grant and Gale (1931, p. 65) mention the overdeepened valleys of the main coastal streams. Most writers have ascribed these features specifically or tacitly to an oscillation of the land up and then down with respect to sea level. However, along this and other continental coasts numerous examples of overdeepened stream valleys have been ascribed to eustatic lowering of sea level.

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This paper discusses certain overdeepened valleys along the coast of Santa Barbara County, California, and describes their relation to the youngest and lowest of several marine terraces. It outlines a sequence of geomorphic events during the late Quaternary which is believed to have resulted in large part from eustatic fluctuations of sea level that accompanied the waxing and waning of maximum glaciation during the Wisconsin stage. The sequence is correlated with similar sequences along other parts of the California coast; and a possible bearing on the time of origin of one so-called submarine canyon is suggested.

ACKNOWLEDGMENTS

The data and observations here discussed were accumulated during an investigation of the ground-water resources of Santa Barbara County by the U. S. Geological Survey in financial coöperation with the County. The writer wishes to acknowledge the aid and criticism of his colleagues both in the course of the work and in the preparation of this paper. Particular acknowledgment for review, criticism, and timely comment is due Prof. U. S. Grant, of the University of California at Los Angeles, Dr. W. P. Woodring of the U. S. Geological Survey, and Prof. A. O. Woodford of Pomona College. The writer is also indebted for criticism and comment to Prof. R. P. Sharp of the California Institute of Technology.

LOCATION OF AREAS

The areas of principal concern in this paper are the main coastal valleys of Santa Barbara County, California, which is on the Pacific coast about 300 miles south of San Francisco Bay and about 80 miles northwest of Los Angeles (see fig. 1). The county is in the right-angled part of the coast formed by two prominent points close together: Point Arguello, from which the coast trends generally northerly, and Point Concepcion, from which the coast trends easterly. In broad outline the coast is regular and simple, but in detail it has a variety of shore-line features. These range from bold headlands, where the shore line transects mountain ridges, to low plains and swamps at the mouths of the rivers and streams and in certain primarily structural basins along the south coast. Along most of the shore, extensive terrace remnants slope seaward to end

at the water or at a narrow beach in abrupt cliffs from 40 feet to several hundred feet high.

The largest coastal valleys are along the lower courses of the two principal streams of the county, the Santa Ynez River

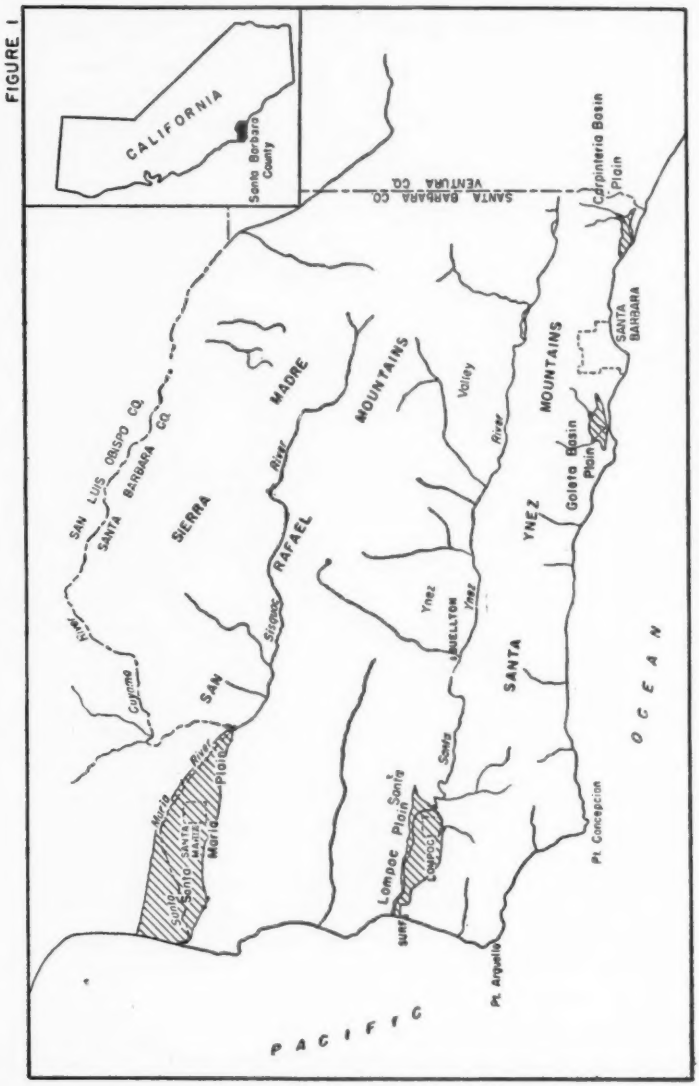


Fig. 1. Index map of Santa Barbara County, California, showing location of main coastal valleys.

and the Santa Maria River, which cross rather broad alluvial plains immediately before entering the sea. The plain of the Santa Ynez River, called the Lompoc Plain, extends about 12 miles inland, and that of the Santa Maria River, called the Santa Maria Plain, extends about 20 miles inland. In addition to these larger coastal valleys, two smaller ones, called the Carpinteria and Goleta Basins, lie along the south coast of the County. These are structural basins originated by faulting, and now contain alluvial plains formed by deposits of several short streams.

In the Lompoc Plain, the Santa Maria Plain, and the Goleta Basin, geomorphic and geologic features indicate a like sequence of events explainable in large part by a eustatic decline and rise of sea level. In the Carpinteria Basin not all elements of the sequence are demonstrable, but the history was probably the same. The pertinent features of the first three areas are described in ensuing paragraphs.

Relative Changes of Sea Level in Santa Barbara County

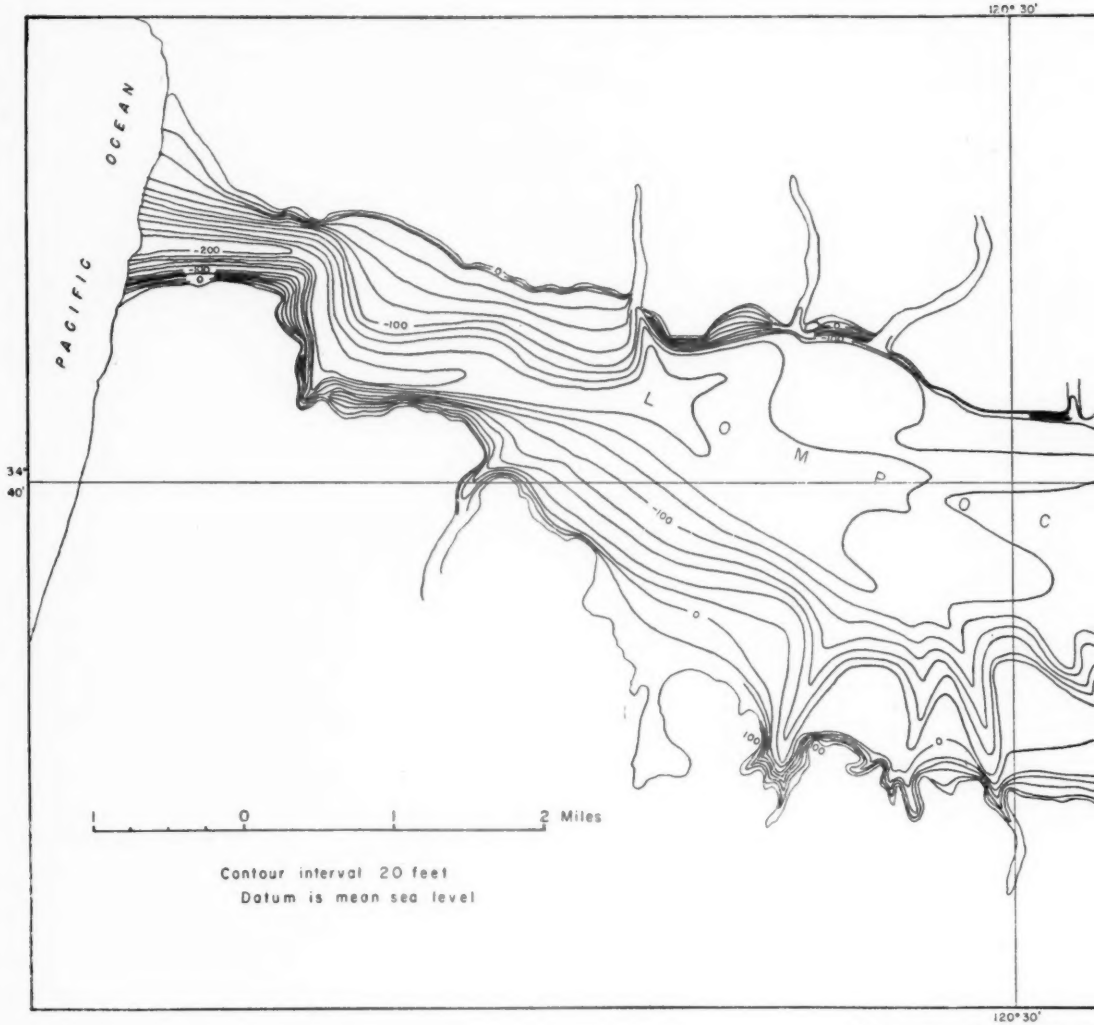
Lompoc Plain

Geomorphic and geologic features

The Lompoc Plain lies in the lowermost part of the Santa Ynez River Valley, between the Purisima Hills on the north, the Santa Rita Hills on the east, and the foothills of the Santa Ynez Mountains on the south. It is a small alluvial plain which extends landward from the ocean for about 12 miles and ranges in width from half a mile to two miles. It is traversed by the Santa Ynez River, which enters the plain at the southeast corner from a narrow valley, called The Narrows, cut in the consolidated rocks (pl. 1, A), then flows westward along the north side of the plain and enters the ocean at the west end.

The geology of this area has been discussed in some detail in a report on the geology and water resources of the Santa Ynez River Valley (Upson and Thomasson, 1947). Considerable information, especially on the pre-Pleistocene deposits, is contained in the paper by Woodring and others (1943) on the Santa Maria district, which includes part of the Purisima Hills. Only certain salient features are summarized here.

The Lompoc Plain is underlain by alluvium, whose thickness and relationships are significant to the discussion in this paper.



MAP OF THE LOMPOC
OF THE LOWER SANTA YNEZ RIVER
SHOWING CONTOURS AT THE BASE

Fig. 2. Map of the Lompoc Plain of the lower Santa Ynez River Valley, C

POC PLAIN
ER VALLEY, CALIFORNIA,
BASE OF THE ALLUVIUM

ey, California, showing contours at the base of the alluvium.

The plain is a series of gently sloping alluvial-fan surfaces, each of which heads in the canyon of its originating river or creek. The surface of the plain thus formed abuts sharply against the sides of the bordering hills and terraces in the fashion characteristic of depositional surfaces. Both the surface of the plain and the Santa Ynez River channel appear to be graded to present sea level, but the river channel is entrenched below the plain surface by a progressively greater amount inland from the shore. Where the river enters the plain, this entrenchment is about 45 feet. Other tributaries on the south also have incised their channels at the margins of the plain in somewhat lesser amounts.

The alluvium occupies a valley which was excavated by the Santa Ynez River in the floor of an older valley now represented by a set of terraces 35 to 90 feet above present sea level and present stream grade. The terraces are capped by alluvial clay, sand, and gravel which rest unconformably on deformed older sediments of Miocene to upper Pleistocene age. Along the southeast and west margins of the plain the alluvium rests on the Monterey shale of Miocene age, but in the middle part of the plain it rests on the relatively unconsolidated marine Careaga sand of upper Pliocene age, the Paso Robles formation of Pliocene and questionable Pleistocene age, and the Orcutt formation of upper Pleistocene age.

These formations have been folded in more or less intermittent deformation with several periods of considerable intensity—the first at the close of Monterey time and the second in the lower Pleistocene after deposition of the Paso Robles formation. Since then some minor warping has taken place, but the Orcutt formation is only slightly tilted, and the deformation appears to be dying out. Within the area of the Lompoc Plain, the deformation developed a syncline whose axis trends southwestward, crossing the Lompoc Plain diagonally. Thus, the Monterey shale at the west end of the Lompoc Plain, which forms the northwest limb of the syncline, moved upward relative to nearby areas during deformation.

Characteristics and origin of the alluvium

In regard to Pleistocene and Recent changes of sea level, the thickness and shape of the alluvium and its relations to underlying formations are critical. About 110 water wells

have been drilled below the surface of the Lompoc Plain; nearly all completely penetrate the alluvium and pass a short distance into the underlying formations. In most well logs these underlying formations are readily recognizable; and thus the base of the alluvium is accurately determined at about 100 points. Figure 2 is a contour map of the base of the alluvium based on the altitudes of these points. This map shows that the alluvium fills an old valley which is somewhat narrower than, but roughly corresponds to, the present valley. The old valley extends outward from The Narrows as a narrow, elongate trench, broadens somewhat beneath the central part of the alluvial plain, where it was excavated in the unconsolidated Careaga sand and Paso Robles and Orcutt formations, and then narrows seaward to a fairly narrow, steep-walled canyon in the consolidated Monterey shale bordering the seaward part of the present plain. Smaller tributary canyons can be rudely traced to the mouths of present-day tributaries entering the south side of the valley. The walls of the old valley are relatively steep, and they more or less continue the slopes of the present valley walls against which the alluvial fill was laid. The alluvium ranges in maximum thickness from about 190 feet at the head of the valley to over 200 feet at the seaward end. The base of the alluvium at the present shore line is not precisely known from well records but the gradient of the base up-valley, averaging 10 to 12 feet per mile, is sufficiently well fixed so that it can be projected from the nearest known points the remaining two miles to the shore with fair accuracy. The base of the alluvium and hence the valley floor at the deepest point is determined to be nearly 220 feet below sea level at the present shore line.

The well logs also show many of the characteristics of the alluvial fill itself. The deposits comprise two sharply defined members. The lower member is of coarse gravel which contains rounded cobbles and boulders as well as some sand, and constitutes a continuous, linear body filling the lower part of the old filled valley. It is 60 to 80 feet in maximum thickness and doubtless represents the channel deposit of the old river. The upper member is composed predominantly of fine-grained material—sand, silt, and clay. As indicated by the well logs, these deposits are lenticular and the various classes of deposits interfinger. Sand and silt seem to pre-

dominate in the headward and marginal parts of the valley, and clay and silt in the central and seaward parts. No clay beds seem to be continuous across the entire valley, and no marine shells are reported in the well logs. Therefore, it seems that beds of marine or lagoonal clay are rare or absent entirely and essentially all the deposits are stream-laid.

The Lompoc Plain is actually the lowest and youngest of a descending series of valleys. The inter-meander spurs and bordering hills in and immediately upstream from The Narrows have flat summits capped by terrace gravel at three levels (see pl. 1, B) the lowest of which is about 90 feet above present stream grade in The Narrows. The remnants are capped by as much as 30 feet of stream-laid gravel; hence the cut surface is about 60 feet above stream grade. Farther upstream it is locally somewhat less than 60 feet. In the gravels of this terrace several miles upstream, near Buellton, the writer found a fossil thigh bone which has been identified by the late C. W. Gilmore as belonging to the genus *Camelops*, thus dating the deposit as Pleistocene.

Downstream, principally along the north border of the Lompoc Plain, this low stream-cut terrace can be traced almost continuously to the ocean, where it merges with a low wave-cut terrace. This terrace is a sloping bench, in part now blanketed by windblown sand and a thin layer of shore deposits. At most places the deposits are not exposed, but they do crop out at the south side of the mouth of the Lompoc Plain where the road climbs to the town of Surf. Here the deposits are composed of lenses of thin-bedded silt, sand, and gravel, with a layer of coarse gravel at the base which truncates dipping shale beds of Miocene age. The base is about 35 feet above sea level at this place, but away from the river mouth the inland edge of the terrace base is somewhat higher.

From the evidence presented in the foregoing, the following sequence of events in late Quaternary time is outlined. The Santa Ynez River developed a cut terrace graded to a marine terrace roughly about 60 feet above present level. Then base level declined and the river excavated a valley graded to a point at least 220 feet below present sea level. Finally base level rose, causing the Santa Ynez River and tributary streams to aggrade their channels, and alluvium was deposited in that valley, filling it to a level graded about to present sea level.

Except for entrenchment in the upper end of the alluvial plain to a maximum depth of about 45 feet in The Narrows, the deposition of the alluvium is the last event in the area. The alluvial filling occurred after the development and strong dissection of the lowest terrace, which is of Pleistocene age, and thus is late Pleistocene or Recent in age.

SANTA MARIA PLAIN

Geomorphic and geologic features

The Santa Maria Plain is about 15 miles north of the Lompoc Plain. It is similar to, but larger than, the Lompoc Plain, and is much wider at the coast. It is the alluvial plain of the Santa Maria River, which is formed by the junction of the Cuyama and Sisquoc Rivers at the head of the plain. The plain extends inland about 20 miles, and is about 10 miles in maximum width. Its topographic and geologic features have been described in a report on the geology and groundwater resources of the Santa Maria Valley area, by G. F. Worts, Jr. (1947), and also by Woodring and others (1943).

The stratigraphy and geologic history are essentially the same as for the Santa Ynez Valley. The plain is underlain by alluvium which was deposited in a valley cut below a series of river terraces, the lowest of which is about 40 feet above the plain. The alluvium and deposits capping the terraces rest unconformably on the Orcutt formation of upper Pleistocene age, the Paso Robles formation of Pleistocene (?) and Pliocene age, and the Careaga sand of Pliocene age; also on the Foxen mudstone and Sisquoc formation of Pliocene and upper Miocene age, the Monterey shale of Miocene age, and locally on the Franciscan formation of Jurassic (?) age and the Knoxville (?) formation of Upper Jurassic age. Some deformation took place in the early Pliocene, as in the Lompoc area, but the principal Cenozoic deformation took place in the lower or middle Pleistocene after deposition of the Paso Robles formation. Later in the Pleistocene slight warping tilted beds of the Orcutt formation, but since then no appreciable deformation has occurred. Thus, since early Pleistocene time diastrophism has been on the wane.

The Santa Maria Plain, like the Lompoc Plain, is on the site of a major syncline. However, here the axis trends northwesterly and passes seaward beneath the broad west end of

the plain. Thus, movement of the valley area near the shore has been, and any tendency for late movement probably would be, consistently downward.

Characteristics and origin of the alluvium

In the Santa Maria Plain the alluvium is less readily distinguished from the underlying deposits than in the Lompoc Plain, but reliable data are at hand from nearly 500 water and oil wells that penetrate the alluvium. These show that the alluvium was deposited in a valley whose lowest point near the ocean is about 230 feet below sea level. The alluvium comprises two members: an upper member of fine sand, silt, and clay that extends inland from the ocean 10 to 12 miles where it grades into the other member of coarse sand and gravel. The sand and gravel member comprises the lower part of the formation near the coast, but the entire thickness inland. The enclosing valley was carved below an older erosional level whose existing terrace remnants are some 40 to 100 feet above the alluvial plain and which is correlated with a low marine terrace along the ocean. The marine terrace is probably the equivalent of the low terrace at the mouth of the Santa Ynez River.

Thus, the sequence of events in the Santa Maria Valley is the same as in the Lompoc area. Streams developed an erosional plain, the youngest in a series of such plains; then with a decline of base level they trenched a valley graded to a sea level at least 230 feet below present sea level; and finally, with a rise of base level, they deposited alluvium in the valley and filled it to a surface graded to present sea level.

GOLETA BASIN PLAIN

Geomorphic and geologic features

The Goleta Basin contains a small alluvial plain about eight miles long from east to west and about three miles in maximum width, which, together with bordering foothills and terraced areas, lies along the south flank of the Santa Ynez Mountains (see pl. 2, A). This alluvial plain is open to the ocean only in a very narrow gap. Along its south (seaward) side, the plain is bordered by a nearly continuous block of deformed Miocene and Pliocene deposits which are truncated by a low marine terrace. Seven sizable streams flow from the mountains and

cross the alluvial plain. Near the south side of the plain these streams join into two main channels across the coastal terrace. The channels pass on either side of Mescal "Island"—a small, round, flat-topped remnant of the coastal terrace once isolated by sea water, but now connected to the surrounding terrane by alluvial fill. South of the "Island" the two channels join to form one just before entering the ocean (see pl. 2, B).

The geology of the Goleta Basin has been described in some detail elsewhere (Upson, 1947). The alluvial plain is underlain by alluvium which occupies a valley system excavated by streams below a broad wave-cut plain of which the coastal terrace is the principal existing remnant. This terrace, and higher, older terraces, are cut across deformed rocks which range in age from Eocene to lower Pleistocene. The terrace deposits are considered to be upper Pleistocene in age, and are very little deformed if at all. The terrace deposits, and the alluvium of the plain, rest on unconsolidated marine clay, silt, and sand comprising the Santa Barbara formation of lower Pleistocene age. This formation has been rather strongly deformed—and has been displaced 1,000 or more feet by movement along faults. The Santa Barbara formation, and locally underlying marine clay and silt of upper Pliocene age, in turn rest unconformably on older marine and continental deposits that range in age from Eocene to Miocene. Locally, the Pliocene and Pleistocene sediments are absent and the alluvium rests unconformably on these older formations.

Thus, there have been two periods of deformation in late Tertiary and Pleistocene time—one in the upper Miocene or lower Pliocene following the deposition of the Monterey shale and the other after the deposition of the lower Pleistocene Santa Barbara formation. Earthquakes in the region attest to the continued presence of crustal stresses, but since the post-Santa Barbara deformation, earth movements have apparently been on the decline.

With respect to the current study, the principal result of the post-Santa Barbara deformation was the uplift of the Monterey shale along a reverse fault or fault zone, with upthrow to the south, which about parallels the present shore on a west-trending, curving trace concave to the north. The zone has been called the More Ranch fault by Hill (1932). It lies half a mile to a mile north of the shore and passes along the north side of the coastal terrace, which is cut across the

Monterey shale. This uplifted shale constitutes the south limit of the alluvial plain with the exception of the gap south of Mescal "Island." Thus, the alluvium of the main part of the plain rests on the unconsolidated Santa Barbara formation north of the fault, but in a narrow strip at the south edge of the plain south of the fault, it rests on the consolidated Monterey shale. Furthermore, any late diastrophic movements along the old structural lines would presumably comprise relatively upward and not downward movement of the coastal terrace block along the shore. The significance of these two features is brought out in subsequent paragraphs.

Characteristics and origin of the alluvium

Here, as in the other areas discussed, the thickness and characteristics of the alluvial fill underlying the plain are known primarily from logs of water wells. In the logs the base of the alluvium is fairly readily distinguished from the underlying Santa Barbara formation, which is characterized by distinctive shells of marine mollusks. Sufficient data are not at hand accurately to contour the base of the alluvium, but together with other general information they are adequate to show that the alluvium occupies a valley system which was graded to sea level at a lower position than the present, as in the other areas discussed in this paper. Several logs of oil-prospect holes drilled on a sand spit across the buried outlet disclose a body of sand and gravel overlying the consolidated shale and extending to an approximate maximum depth of 225 feet below sea level. It is inferred that this sand and gravel are the deposits of an older stream system which traversed the Goleta Basin and carved valleys whose currently recognizable low point is about 225 feet below present sea level. Most of the alluvial fill is composed of clay and silt; and any extensive lower member of gravel such as those underlying the Lompoc and Santa Maria plains seems not to exist.

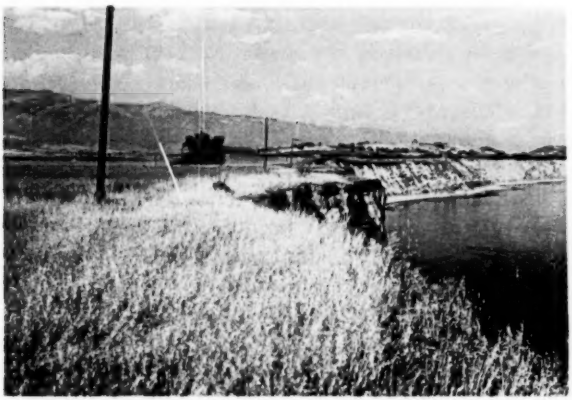
A corresponding sequence of events doubtless also occurred in the Carpinteria Basin, about 20 miles east, but the history there evidently was complicated by continuing movement along coastal faults. Also, the coastal barrier of Tertiary shale is missing along the coast south of the western half of the basin. Deposits which predate the alluvium are not readily distinguishable in well logs from the alluvium; and a prealluvial valley system, though recognizable near the mountains, cannot be traced seaward across the plain.

A. View northwest down Santa Ynez River channel at The Narrows. Hill at left and terrace remnant at extreme right are composed of Miocene shale. To right of brushy river channel is a plowed field on 15-foot alluvial terrace and farther right the walnut grove is on a 45-foot alluvial terrace continuous with the alluvial plain in the distance.

B. View northwest along meandering channel of the Santa Ynez River immediately above The Narrows. Meanders incised in Miocene shale cut by three terraces on right skyline. The lowest terrace is equivalent to the low marine terrace at the coast. Channel is underlain by alluvium to a maximum depth of about 145 feet.

A. Alluvial plain of the Goleta Basin. View north from the coastal terrace; Santa Ynez Mountains in background.

B. View east in outlet of Goleta Basin plain; from a point south of Mescal "Island", and about at the confluence of the two channels flanking the "Island". The cliff nose just left of center is the east side of the gap. It is composed of steeply dipping Miocene shale truncated by marine terrace deposits. Shore deposits and alluvium below the camera site have a maximum thickness of about 200 feet.



A. View east along surface of marine terrace and sea cliff from point about 1 mile east of site of plate 2, B. Veneer of flat-lying deposits truncates north-dipping Pliocene marine beds. Santa Ynez Range and east end of Goleta Basin at left.

B. Terrace deposits on low wave-cut platform truncating steeply dipping Monterey shale near Naples, about 8 miles west of Goleta Basin.

In the Goleta Basin the old, now buried, valleys were cut below an erosional surface, which was probably almost entirely a marine wave-cut platform. This surface is revealed by extensive level surfaces (pl. 3, A) that are seen to level the contorted shale of the coastal block. That these are remnants of a marine platform is indicated by the capping deposits, which consist of a basal layer of coarse gravel and sand locally containing marine shells, and an upper body of silt, sand, and poorly sorted gravel in distinct but irregular lenses (See pl. 3, B). The basal layer of coarse gravel and sand rests with sharp contact on the beveled edges of the underlying deformed beds, and locally these and the boulders have the characteristic rounded pits and depressions bored by pholads. The deposits of the upper unit are composed of poorly sorted, irregularly stratified clayey and silty sand with lenses and zones of sandy gravel. Hence they were probably laid down by streams, although locally there are lenses of fairly well sorted sand that may be marine in origin. At a few localities fossil bones have been found in the upper deposits. In a cut along the Southern Pacific railroad near Capitan, about 12 miles west of the Goleta Basin, track workmen discovered the lower jaw of a mammoth which fortunately was observed in place and removed by Phil C. Orr, Curator of Vertebrate Paleontology and Anthropology of the Santa Barbara Museum of Natural History, who identified the jaw as belonging to *Archidiskodon imperator*. This fossil was found about 15 feet below the top of the deposits in the bottom of a lense of gravel. It is not badly worn and therefore probably was neither transported far before burial, nor eroded from other beds and redeposited. Accordingly, it is thought to represent the age of the deposits in which it was found, which are therefore considered Pleistocene, and together with their lithologic character shows that the deposits are continental.

This terrace extends east and west for several miles from the Goleta Basin, and it is represented by broad, gently sloping or nearly flat remnants. It has been called the Santa Barbara terrace by Grant and Gale (1931, p. 39), who studied fossil shells from the basal deposits; and has been correlated by Davis (1933, p. 1109) with his Dume platform along the coast of the Santa Monica Mountains.

The terrace remnants, where undisturbed, have a seaward slope formed mainly by the surface cover of continental de-

posits. The wave-cut platform also slopes seaward, but at a lesser angle; and its landward edge, which theoretically should abut against a wave-cut cliff (Davis, 1933) is ordinarily covered by the alluvium. Also, the seaward edge has been eroded back various distances by the Recent sea. Accordingly, the altitude of the surface varies from place to place; and at most places it is impossible to determine the altitude of the peak shore line represented by the platform. At the mouth of the Goleta Slough (pl. 2, B) the wave-cut platforms of the terrace is about 60 feet above sea level. At Goleta Point, about one mile to the southwest, it is about 35 feet. Remnants of this terrace also occur along the inland margins of the Goleta Basin, but there the alluvial cover conceals the actual eroded platform, and its elevation is not known. Farther west, where U. S. Highway 101 crosses the east side of the valley of Tecolote Creek, the eroded platform can be seen in a cut on the old highway some 40 feet above the present highway. The elevation of the platform here, which is about a quarter of a mile from the shore, and a somewhat lesser distance from the inland edge of the terrace, is about 80 feet. The platform is probably somewhat higher inland, but must be appreciably below the surface of the alluvial cover, whose elevation as estimated from the contours of the Goleta quadrangle is about 150 feet. Thus, the maximum height of the wave-cut platform is probably close to 100 feet above sea level.

Thus, the late geomorphic sequence in the Goleta Basin is as follows: waves cut a marine platform 35 to about 100 feet above present level, then streams cut a valley system, with an outlet through the coastal barrier of shale, graded to a position of sea level at least 225 feet below present sea level. Then with a relative rise of the sea this valley was filled with alluvium about to the present sea level. This seems to be unquestionably the last event of the three, and evidently it continued until very recent time because old residents report that 60 years ago tidal water was sufficiently deep near the present middle of the alluvial plain that ocean-going vessels docked at the town situated there.

Summary of the Geomorphic Sequence on the Santa Barbara County Coast

At three places along the Santa Barbara coast: the lower part of the Santa Ynez River Valley, the lower part of the

Santa Maria River Valley, and the Goleta Basin, waves developed a marine terrace at a maximum present elevation of about 100 feet. With retreat of the sea, streams first deposited alluvial debris in sloping cones and fans on the marine platform, but later entrenched their courses and cut valleys graded to a relatively lowered sea level. At its lowest position that sea level was at least 220 and probably 300 feet below present level. The major streams cut the deepest and largest valleys, but smaller streams also cut steeper, shallower valleys. Subsequently, with a relative rise of sea level, these valleys were filled with alluvium whose upper surface seems to slope evenly about to present sea level.

The cutting of the low marine terrace is the first event in the sequence; and is the least clearly defined. The terrace remnants have been traced along the Santa Barbara coast by reconnaissance only and there may be some errors in correlation. However, it is believed that the low terrace remnants here discussed represent the same event of marine abrasion.

The magnitude of the relative decline of sea level as measured from the approximate elevations of the marine terrace at the shore is 270 feet for the Santa Maria Plain, 255 feet for the Lompoc Plain, and 285 feet for the Goleta Basin. From a peak shore-line level of 100 feet, the maximum declines measured at the shore would be 330, 320, and 325 feet, respectively. As is discussed in the next paragraph, the actual maximum declines are probably somewhat greater.

At the time of maximum decline the shore must have been some distance seaward from the present shore, and streams flowing to it must have had some gradient. Hence the outermost part of the stream courses must have been somewhat lower than the 220- to 230-foot depths at the present shore. As is shown beyond, the Santa Ynez River was probably graded to a point about 300 feet below present sea level. This point corresponds closely with the outer edge of a submerged shelf bordering a large part of the Santa Barbara County coast and also much of the coasts of the Santa Barbara Channel Islands as shown on U. S. Coast and Geodetic Survey Chart 5202. The edge of this shelf is in the neighborhood of the 50-fathom line, or about 300 feet below sea level. This bench has been recognized by other writers on the California coast; and Shepard and Emery (1941, Charts I-IV) show the bench, somewhat discontinuous and of greatly varying width, along

the entire California coast. It can hardly represent anything other than a stand of the sea at a maximum of 300 feet below present level; or, for the Santa Barbara coast, about 400 feet below the highest point of the lowest marine terrace now above sea level.

The magnitude of the relative rise to present sea level as measured at the shore is 230 feet for the Santa Maria Plain, 220 feet for the Lompoc Plain, and 225 feet for the Goleta Basin Plain. The agreement strongly suggests that the relative rise was an actual rise of sea level against an essentially stable coast and not a depression of the land. This conclusion is strengthened by the facts brought out in foregoing paragraphs, namely: (1) that differential deformational movements have been slight in late Pleistocene and Recent time in this area, and (2) the directions of any late local differential movements at the mouths of the valleys, if in accord with preexisting structures, would be downward beneath the Santa Maria Plain, but upward beneath the seaward parts of the Lompoc Plain and the Goleta Basin, and hence of no consistent direction for the whole coast. Thus it is concluded that local distrophic movements along existing structures could not have caused the relative rise of sea level.

Correlation with Other Areas Along the Pacific Coast

In the vicinity of Long Beach, California, a similar sequence of events has been described by Poland and others (1945). There streams carved valleys to a depth of about 150 feet at the present shore. The profiles of these valleys project seaward to correspond approximately to a submerged shelf interpreted to be a marine platform, whose inner and outer margins are at depths of about 120 and 240 feet below sea level, respectively. The valleys were evidently cut by streams graded to the sea at the lower level.

Along the coast of San Diego County, Ellis and Lee (1919, pp. 71 and 111-118) describe coastal valleys filled with alluvium whose base extends considerably below sea level. For example, records of wells in the lower parts of the Tia Juana, Mission, and San Diego Valleys (names derived from the respective streams) along the coast between San Diego and the international boundary show that the alluvial fill extends

downward to maximum depths of about 100 feet below sea level at the shore. Grant and Hertlein (1944, p. 28) report similar depths of alluvium from a geophysical survey of the Tia Juana Valley. As in the Santa Ynez and Santa Maria Valleys, the alluvium comprises a lower member of coarse gravel and an upper member of finer-grained deposits. Farther north, near the mouth of the San Luis Rey Valley, the base of the alluvium is nearly 200 feet below sea level. The more southern valleys now empty into the ocean in San Diego Bay or Mission Bay, actually some distance back from the open ocean, whereas the San Luis Rey Valley enters the sea at the open coast. Accordingly, it is likely that the depth of fill in that valley is more nearly representative of the true relation between land and sea at the time of valley cutting.

The account of Ellis and Lee (1919, pp. 71, 75, and 110-112) is somewhat obscure as to the precise sequence of events along the coast of San Diego County. However, the latest events postulated by these authors seem to have been relative uplift of the land some 200 feet above present elevation and excavation of stream valleys. This was followed by submergence and filling of the valleys to the present levels of the valley floors. Marine terraces were apparently developed during the earlier uplift. Grant and Hertlein (1944, p. 31) suggest that the valley cutting may have been followed by a rise of sea level to about 100 feet above present level. However, inspection of topographic maps and observations made during a brief trip along the San Diego coast suggest to the writer that the 100-foot stand of the sea preceded the valley cutting, and that the sequence corresponds to that along the Santa Barbara coast.

North of Santa Barbara County similar features are known. Data on the Salinas Valley contained in a report on that area by the Division of Water Resources of the California Department of Public Works (1947) suggest that a similar alluvial valley, graded to a position 200 feet below sea level, may exist in the lower course of the Salinas River. Also, the stream system entering San Francisco Bay once flowed through the Golden Gate, whose maximum depth is about 350 feet below present sea level. Finally, a geomorphic sequence on the Oregon Coast having similar elements has been described by Baldwin (1945). In Oregon the valley of the Coquille River contains a deep fill

of alluvium which apparently occupies a narrow valley excavated below a low marine terrace. This terrace has a maximum height of 225 feet above sea level and is capped by late Pleistocene deposits called the "Elk River beds." The sequence here is more complicated than in Santa Barbara County, California, because the low terrace is reported to be tilted, and it also truncates an older estuarine fill called the Coquille formation. The Oregon sequence cannot be surely correlated with the California sequence on the basis of existing data, but the similarity is striking and may be significant.

Thus, along most of the California portion of the Pacific Coast, at least, and possibly also the Oregon portion, streams have apparently carved older valleys below a low marine terrace. These valleys are apparently graded to a relative position of sea level that ranges from 120 to 300 feet below present level. It appears that the larger figure represents the maximum decline of sea level below the present level. These figures, especially the maximum 300 feet, are of the same order as figures assembled by Antevs (1928, p. 82) and more recently by Flint (1947, pp. 446-447) for various parts of the world. Stearns (1935, p. 1934) has presented similar evidence for a 300- to 360-foot stand of the sea below present level on Oahu and other islands of the Hawaiian group.

Origin and Age of the Geomorphic Sequence

The earliest event of the sequence here described, cutting of the low marine terrace, is considered late Pleistocene in age. The mammoth jaw at El Capitan and the camel femur in the alluvial terrace deposits along the Santa Ynez River suggest this age. Grant and Gale (1931, p. 39) concluded that the marine invertebrates in the lowermost deposits in the terrace near Goleta represent a late Pleistocene age. Grant and Strong (1934) considered that mollusks in tar-impregnated terrace deposits near Carpinteria, probably the same low terrace discussed in this paper, indicate a late Pleistocene age. Finally, Woodring and others (1946) consider all the terraces on the Palos Verdes Hills to be upper Pleistocene. Marine terraces cannot be precisely dated on the basis of contained fossils. Nevertheless, in the Goleta Basin, the low terrace here considered truncates deformed beds of the Santa Barbara formation of which the

lower part is considered upper Pliocene by some geologists (Bailey, 1943, p. 1562); but whose upper part is considered lower Pleistocene by most geologists (see Woodring and others, 1940).

The low terrace must have been developed after the deformation of the Santa Barbara beds, which took place in lower or middle Pleistocene time (Bailey, 1943). Furthermore, it is the lowest and youngest of several terraces along the Santa Barbara coast; description of the higher and older ones of which is beyond the scope of this paper. In order to allow time for a major deformation and the cutting of several older marine terraces in post-lower Pleistocene time, the formation of the low terrace and the initiation of the geomorphic sequence here discussed are considered upper Pleistocene. The geomorphic sequence evidently ends in Recent time with the deposition of alluvium as essentially the latest geologic event of the region. Thus, together with the additional evidence summarized beyond, the intervening valley cutting is considered to have resulted largely from the lowering of sea level that accompanied the maximum glaciation during the Wisconsin stage. The low marine terrace may have been formed in the immediately preceding, or Sangamon, interglacial stage.

In regard to origin, the rise of sea level from the lowest position in the sequence to about the present level is considered eustatic because of its nearly equal magnitude throughout Santa Barbara County, its indifference to the probable direction of local crustal movements, its correspondence in magnitude with similar relative rises of sea level along the rest of the California coast, and its agreement with corresponding relative rises in other parts of the world. Now, if the rise of sea level is a eustatic rise in accord with the waning of a glacial stage, then the immediately preceding lowering of sea level must be in large part eustatic, resulting from a waxing of the same glacial stage and perhaps one or more preceding stages. The writer uses the words "in large part eustatic" because the low marine terrace has not been mapped carefully, its elevation along the coast has not been determined precisely, and it may be slightly deformed at places. A "200-foot" terrace (Putnam, 1942, p. 741) near the west end of Rincon Mountain slopes westward beneath the Carpin-

teria Basin—apparently tilted. Tilted low marine terraces have been reported at other localities along the California coast. (See Woodring and others, 1946, p. 115 and pl. 26.) However, for many miles along the coast west of the Carpinteria Basin in Santa Barbara County the low terrace certainly is not deformed very much; and it is believed that at least 300 feet, and probably more, of the relative decline of sea level from this terrace was a eustatic lowering of sea level and only a small part of the total difference in elevation can be accounted for by a rise of the land.

The writer does not wish to imply that all terraces older than the 100-foot terrace of this paper are also wholly or even in large part the result of eustatic fluctuations of sea level correlative with glacial stages. At some other localities along the California coast, older terraces are too numerous to be accounted for in this way, for example, on the Palos Verdes Hills, where Woodring, Bramlette, and Kew (1946, pp. 113-116) have described 13 terraces, and on Rincon Mountain, where Putnam (1942) has described 9 elevated terraces. At these localities some of the terraces are tilted, as has been mentioned, and the tilting may be the local expression of more widespread upward crustal movements. Davis (1933) ascribed the preservation of elevated marine terraces of the Santa Monica Mountains largely to uplift, but their origin to eustatic shifts of sea level which he correlated with a hypothetical set of glacial stages. Discussion of the origin and uplift of older terraces of the Santa Barbara coast is beyond the scope of this paper. If, following the lower or middle Pleistocene period of diastrophism, the land continued to rise but at a decreasing rate, the formation of marine terraces developed during the uplift may have been due primarily or entirely to temporary halts during the uplift and may have no genetic relation to glacial stages. On the other hand, to ascribe the origin of the late Pleistocene and Recent cut and fill of the coastal streams, here discussed, to uplift of continental proportions followed by a reversal on the same scale, seems unreasonable.

Relation to the Origin of Submarine Canyons

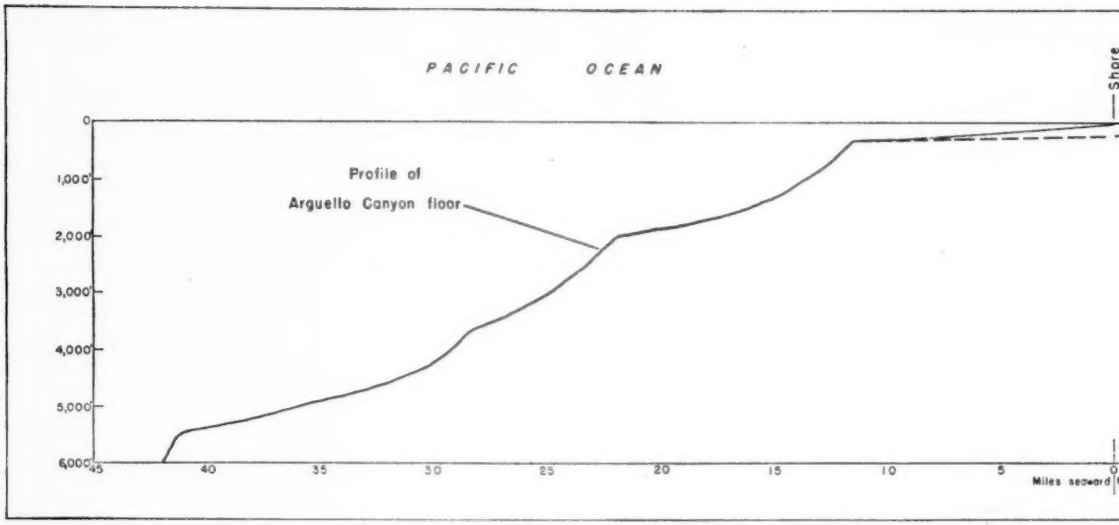
The writer believes that the age and origin of the geomorphic sequence here described has a bearing on the problem

of origin of so-called submarine canyons. Off Point Arguello is a minor submarine canyon that heads in four distinct tributaries, one of which seems to be a seaward extension of the Santa Ynez River Valley. This canyon has been called Arguello Canyon by Shepard and Emery (1941), who have described it and others off the California coast.

Figure 3 shows a longitudinal profile of Arguello Canyon above a depth of about 6,000 feet, and a profile of the base of the alluvial fill of the Santa Ynez River. The profile of Arguello Canyon is taken from U. S. Coast and Geodetic Survey chart 5202, dated December 1940. The profile of the base of the alluvium is from well logs and dam-site corings (Upson and Thomasson, 1947, pl. 509). The profiles include distances of about 45 miles seaward and landward, respectively, from the shore. The lines are solid where based on specific data but broken where inferential. The profile of the Santa Ynez River Canyon is well controlled downstream at least to a point about 2 miles from shore. Thence it is projected seaward at about the same slope, as it is considered highly improbable that the gradient would steepen appreciably in that distance. Shepard and Emery (1941, pl. 12), and perhaps others, have drawn comparative longitudinal profiles for Arguello Canyon and the Santa Ynez River and for other seemingly contiguous submarine canyons and land valleys. The profile of Shepard and Emery for Arguello Canyon and the Santa Ynez River was evidently drawn on the surface gradient of the river. It happens that the surface gradient is very little different from the suballuvial profile, but it is believed that the difference is significant geomorphically.

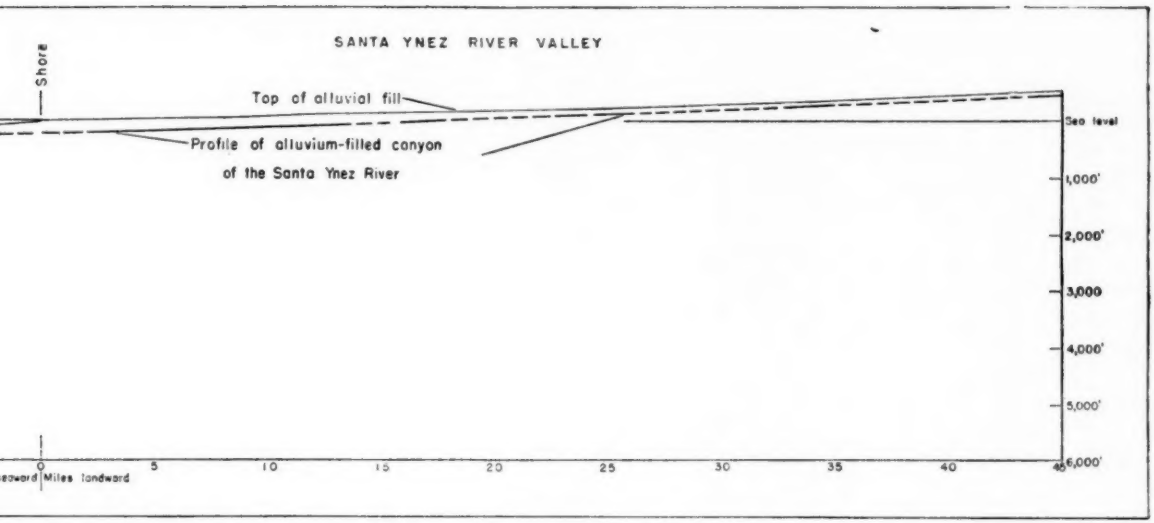
The outstanding features of the profiles here given are (1) the coincidence of the projected suballuvial profile with the outer edge of the submarine bench (now blanketed by shore deposits) at about 300 feet below sea level; and (2) the abrupt steepening of gradient at the head of the profile of Arguello Canyon.

The abrupt change in gradient from the suballuvial Santa Ynez Canyon to Arguello Canyon is a marked physiographic discontinuity. It signifies that the headward part of Arguello Canyon originated in an entirely different geomorphic episode from that in which the prealluvial Santa Ynez River Valley was cut. The discontinuity alone does not indicate which geo-



LONGITUDINAL PROFILES OF ARGUELLO CANY
CALIFO

Fig. 3. Longitudinal profiles of Arguello Canyon



CANYON AND OF SANTA YNEZ RIVER CANYON,
CALIFORNIA

nyon and of Santa Ynez River Canyon, California.

morphic episode is the older. If the two profiles were now above sea level, the suggestion would be strong that the lower profile (that of Arguello Canyon) was the younger, and that the abrupt change in gradient was due to the headward cutting of a stream working in an older valley, but graded to a lower position of base level. However, in the existing case, the suballuvial profile of the Santa Ynez River seems clearly to have been graded to the 300-foot submerged bench which apparently truncates the steep head of Arguello Canyon thus suggesting that the steeper profile is the older. Further, if the suballuvial canyon of the Santa Ynez River was cut in Wisconsin time, as argued above, then Arguello Canyon would have had to be cut in pre-Wisconsin time. There seems to have been neither time nor opportunity for subaerial cutting in post-Wisconsin time; and a submarine process, perhaps now operating, would probably be much slower than any subaerial process. Thus, essentially all of the formation of Arguello Canyon, by whatever process, is believed to have taken place in pre-Wisconsin time.

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THE DISTRIBUTION OF ORGANIC MATTER IN SEDIMENTS FROM THE NORTHERN RED SEA

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ABSTRACT. The importance of additional chemical knowledge of the Red Sea bottom sediments is stressed. Methods used for the determination of organic carbon and nitrogen in thirty-eight sediments from the northern Red Sea are described and the results of analysis are given. The distribution of organic matter in these sediments is discussed.

The following points are revealed by the present investigation. 1. The organic matter content of the northern Red Sea sediments is very small. 2. The C:N ratio, which amounts to 5.2, is low. 3. Both the organic matter content and the C:N ratio exhibit regional variations which are ascribed to different environmental conditions of sedimentation. 4. The mean C:N ratio for these sediments is in close agreement with the proportion of these elements in mixed plankton.

INTRODUCTION

OUR knowledge of the chemistry of the Red Sea bottom sediments has been largely derived from the results of the Austrian Expedition on the "Pola" in 1895-96 and 1897-98. Seventeen bottom samples of the "Pola" collection were chemically investigated by Natterer (1898). His analyses included the estimation of carbonate, organic matter, silica, lime, magnesia and some other constituents. Trask (1932) determined the amount of carbonate and nitrogen in ten bottom sediments from the southern Red Sea. Wiseman and Bennett (1940) estimated organic carbon and nitrogen in two bottom sediments collected from the southern Red Sea by the John Murray Expedition. The results of these investigations comprise all knowledge that is available at present of the chemistry of the Red Sea bottom sediments.

Information concerning the abundance and distribution of organic matter in marine sediments is highly desirable. Such information is of special importance to the oil geologist, since it is widely held that the mother substances of petroleum are found in the organic matter of these sediments. It is also of great interest to the marine biologist, since it is believed that the only available source of nutrition for bottom-living organisms inhabiting deep waters is the organic constituents of these sediments.

The direct determination of organic matter in marine sediments is, however, not an easy task. Soil chemists are con-

fronted with the same problem, but as a result of much investigation they arrived at estimating the organic matter content of a soil by multiplying its organic carbon content by the factor 1.724. It is, however, probable that the organic matter in marine sediments is different in its chemical nature and mode of formation from that in soils. Moreover, the constancy of the ratio of organic matter to organic carbon in marine sediments is uncertain. In view of these objections it is preferable to have recourse to some more reliable means of measuring and comparing the organic matter content of marine sediments. As organic carbon and nitrogen are two of the major constituents of organic matter, their determination would provide such means.

It is therefore the object of this paper to record the results of the chemical estimations of organic carbon and nitrogen determined on bottom sediments collected from the northern Red Sea by an Egyptian Expedition, which sailed on the oceanographic boat "Mabahiss" in 1934-35 (Crossland, 1939; Mohamed, 1940), and then to attempt the interpretation of these results.

METHODS

Collection and storage of samples.—Two types of instruments were used for collecting bottom samples on "Mabahiss": the Bigelow sounding rod and the Petersen grab. After collection, each sample was left for some days to dry in air and was then stored; core samples were wrapped in paper and stored in cardboard tubes, while grab samples were stored in glass jars.

Preliminary treatment of samples.—To render the samples absolutely free of salt, 30 grams of each sample were placed in a Jena glass-sintered filter of the finest grade and were repeatedly washed with distilled water until the filtrate no longer gave a precipitate with silver nitrate. Samples were afterwards dried in a hot air-oven regulated at a temperature of 100°C., and then reduced to fine powder, thoroughly mixed and finally kept in previously cleaned, steamed and dried specimen tubes.

Organic carbon determination.—The content of organic carbon was determined by the gravimetric wet combustion method as described by Morgan (1904) and modified by Dixon (1934)

so as to be more suitable for the determination of organic carbon in carbonate-rich rocks. This method consists in oxidizing the organic carbon by means of chromic and phosphoric acids and then absorbing and weighing the evolved carbon dioxide.

About 2.5 grams of the dried powdered sample were accurately weighed into a 250 c.cm. round-bottomed Pyrex flask fitted with a two-hole stopper. Through one hole a tap funnel was passed and through the other an upward inclined small condenser to retain most of the steam and acid liberated from the flask. The carbon dioxide present as carbonate was first removed by slowly admitting syrupy phosphoric acid into the decomposition flask from the funnel. When effervescence diminished, the flask was heated briskly until all carbon dioxide present as carbonate was expelled. The condenser was then connected with a train of U-tubes as follows:— (1) a tube containing a mixture of phosphoric and chromic acids; (2) a tube containing glass beads moistened with concentrated sulphuric acid; (3) a tube containing pumice impregnated with anhydrous copper sulphate; (4) a calcium chloride tube; (5) two weighed soda-asbestos tubes; (6) a calcium chloride guard tube; (7) a soda-lime tube which acted as a precautionary trap for any moisture or carbon dioxide leaking from the atmosphere. Before the soda-asbestos tubes were placed in position, a stream of CO_2-free air was passed through the apparatus for 15 minutes to sweep away any carbon dioxide which might be present. The apparatus was then fitted together and 20 c.c. of a 10 per cent solution of chromic anhydride in phosphoric acid were run slowly from the funnel. The flask was heated with a small flame while a gentle stream of CO_2-free air was passed through the apparatus. Heating was continued with a gradually increasing flame for about one and half hours. The flame was then extinguished, but the CO_2-free air current was continued to pass through the apparatus for 15 minutes. Finally, the soda-asbestos tubes were removed and weighed, after standing for half an hour in the balance case, against similar tubes as counterpoise.

The organic carbon content of several samples was determined by duplicate analyses and the results agreed within $\pm$ 0.04 per cent. Some typical duplicate results are shown in table 1 following.

TABLE 1

Sample No.	Organic carbon (per cent)	Difference (per cent)
2	0.43, 0.47	0.04
8	0.16, 0.14	0.02
25	0.21, 0.23	0.02
36	0.10, 0.11	0.01

Nitrogen determination. — Nitrogen was determined by the micro-Kjeldahl method. About 2.5 grams of the dried powdered sample were accurately weighed into a micro-Kjeldahl flask; one droplet of mercury was added as a catalyst and 10 – 15 c.c. of nitrogen-free concentrated sulphuric acid were also added very cautiously. Heating was then started with a small flame which was increased gradually and digestion was continued for several hours until decolorization was complete and the precipitated calcium sulphate looked pretty white. The product of oxidation was then filtered into 100 c.cm. measuring flask, the calcium sulphate washed several times with small portions of distilled water and the filtrate made to 100 c.c. The distillation of ammonia and its volumetric determination was subsequently carried out on 10 c.c. portions of this filtrate according to the procedure described by Pregl (1930). Parnas and Wagner's improved micro - Kjeldahl apparatus was used and automatic 10 c.c. micro-burettes graduated to 1/50 c.c. were employed in the volumetric operation.

The nitrogen content of several samples was also determined by duplicate analyses and the agreement between the results was remarkably excellent; these results seldom differed by as much as ± 0.005 per cent.

RESULTS

The results of analysis are tabulated in table 2 below. In the first column the sample number is given, in the second the station number, in the third the geographical position, in the fourth the depth in meters, in the fifth and sixth columns the percentages of organic carbon and nitrogen, and in the seventh the C:N ratio is recorded. Complete list and full particulars of stations are given by Crossland (1939).

Thirty-eight samples were investigated, three of which were procured from the Gulf of Suez, five from the Gulf of Aqaba

and the rest from the adjacent regions of the Red Sea proper. In the case of core samples, estimations were made on the upper parts of the cores.

TABLE 2

Results of organic carbon and nitrogen analysis in sediments from the northern Red Sea.

Sample No.	Station No.	Position: Latitude °	'	"	Longitude °	'	"	Depth (meters)	Organic carbon (%)	Nitrogen (%)	Ratio C:N
(1) Gulf of Suez											
1	1	29	23	30	30	37	00	62	0.35	0.050	7.0
2	2	29	08	15	32	45	30	59	0.45	0.055	8.2
3	3	28	46	45	32	57	15	64	0.38	0.049	7.8
(2) Gulf of Aqaba											
4	49	28	27	24	34	30	18	265	0.06	0.024	2.5
5	52 B	28	32	00	34	40	12	1113	0.08	0.023	3.5
6	54	28	40	30	34	42	18	1393	0.11	0.024	4.6
7	55	28	39	12	34	39	12	442	0.12	0.025	4.8
8	57	28	11	54	34	32	12	1128	0.15	0.033	4.5
(3) Red Sea proper											
(a) Southern approaches of the Gulf of Suez											
9	7	27	30	40	34	03	30	731	0.31	0.049	6.3
10	14	27	19	39	33	48	06	66	0.13	0.029	4.5
11	18	27	19	18	33	49	06	71	0.15	0.042	3.6
12	19	27	17	54	33	50	12	102	0.39	0.052	7.5
13	20	27	22	06	33	46	15	18	0.19	0.029	6.6
14	21 A	27	26	42	33	45	33	73	0.35	0.091	3.8
15	22 C	27	16	24	33	51	18	102	0.38	0.082	4.6
16	23 C	27	18	24	33	52	36	93	0.11	0.025	4.4
17	26	27	27	48	33	54	18	236	0.11	0.041	2.7
18	28 A	27	29	00	33	53	24	118	0.14	0.052	2.7
19	32 F	27	16	30	33	52	12	102	0.24	0.058	4.1
20	34 A	27	23	24	33	56	30	124	0.11	0.030	3.7
21	34 E	27	23	42	33	57	12	88	0.07	0.028	2.5
22	34 H	27	24	03	33	57	48	144	0.09	0.024	3.8
23	34 L	27	23	30	33	57	42	440	0.30	0.072	4.2
24	37	27	24	48	33	59	15	366	0.19	0.039	4.9
25	40	27	34	36	34	00	51	941	0.22	0.086	2.6

(b) Southern approaches of the Gulf of Aqaba

Sample No.	Station No.	Position						Depth (meters)	Organic carbon (%)	Nitrogen (%)	Ratio C:N
		Latitude			Longitude						
		°	′	″	°	′	″				
26	41 H	27	54	57	34	37	38	24	0.09	0.044	2.0
27	42	27	49	30	34	39	30	741	0.12	0.032	3.8
28	43	27	52	00	34	27	24	1147	0.21	0.041	5.1
29	58	27	51	30	34	38	12	596	0.20	0.055	3.6

(c) Open region of Red Sea

30	45 A	27	39	30	34	23	30	960	0.09	0.016	5.6
31	67	27	08	42	34	10	00	814	0.18	0.031	5.8
32	76	26	57	36	34	23	36	951	0.15	0.030	5.0
33	77	27	05	24	34	37	00	1274	0.13	0.023	5.7
34	78	27	13	21	34	50	12	1148	0.11	0.019	5.8
35	81 B	26	48	30	35	40	36	873	0.15	0.028	5.4
36	82 A	26	38	00	35	21	30	834	0.11	0.018	6.1
37	83	26	34	33	35	03	45	1234	0.29	0.047	6.2
38	86	26	13	15	34	36	12	667	0.13	0.024	5.4

DISCUSSION

Before discussing the above results a short survey will be given of the chief factors which determine the content of organic matter in marine sediments. These factors include the supply of organic matter, its transportation by currents, its rate of sedimentation and the extent of its decomposition as well as the configuration of the sea bottom and the texture of the sediments.

In deep and open waters the supply of organic matter depends mainly on the abundance of phytoplankton, while in coastal waters sedentary vegetation is, as a rule, the chief source of organic matter. The plankton productivity of an area depends on a number of factors such as light, temperature, turbulence, the concentration of nitrate and phosphate and other nutrients, and the presence of iron and some other minor constituents in sea water. Consequently, the supply of organic matter will be abundant if the conditions of plankton productivity are favorable. But it does not follow that the underlying sediments will be rich in organic matter, since the transporting influence of the currents may carry organic residues considerable distances. Furthermore, the supply of

organic matter may be identical in two areas, yet their sediments may differ in their content of organic matter if there are different rates of deposition of inorganic detritus.

The amount of decomposition which takes place in organic debris before and after sedimentation exerts also a great influence. Before sedimentation, the amount of decomposition depends on the quantity of dissolved oxygen in the water; the smaller the supply of oxygen, the richer is the organic matter content of sediments. It also depends on the depth of water through which the organic debris may sink; the deeper the water, the longer the interval required to reach the bottom and the greater is the amount of decomposition. After deposition, organic debris will continue to decompose through the agency of microörganisms. The extent of this decomposition is largely dependent on the oxygen content of bottom water.

Finally, the configuration of the sea bottom and the texture of the sediments were found to have a profound influence on the organic matter content of sediments. Trask (1932) found that sediments in depressions contain more organic matter than do those on ridges and slopes. He also found that the organic matter of sediments increases as their texture becomes finer.

As to the topography of the area investigated, it is to be noted that the differences between the Gulf of Suez and the Gulf of Aqaba, into which the Red Sea bifurcates at its northern end, are striking. The Gulf of Suez is a shallow flat-bottomed shelf with an average depth of 50 meters, while the Gulf of Aqaba is a deep trough with depths up to 1830 meters in the middle of the Gulf. Moreover, the Gulf of Suez descends at its mouth abruptly to a depth of over 300 meters in the Strait of Jubal, while the Gulf of Aqaba is separated from the deep parts of the Red Sea by a shallow sill in the Strait of Tiran. The Red Sea itself, which is of considerable depth, is studded in places with rocky islets and is characterized by the irregularity of the bottom and the occurrence of submarine hills. No rivers flow into the Red Sea, and the northern part is rainless.

In the light of all these considerations the distribution of organic matter in sediments from the northern Red Sea will be discussed. The organic carbon content as well as the

nitrogen content will be used as the basis for describing and comparing the organic matter content of the investigated sediments.

Distribution of organic matter.—The most striking result of the present investigation is that the organic matter content of sediments from the northern Red Sea is very low compared with that of other marine sediments; the organic carbon content ranges from 0.06 to 0.45 per cent and the nitrogen content from 0.016 to 0.091 per cent. Granted that the organic matter content of sediments is an index of productivity, these figures would clearly indicate that organic production in the northern part of the Red Sea is very poor on the whole.

Regarding the distribution of organic matter in the different regions of the investigated area it is found that the organic matter content of sediments from the shallow Gulf of Suez is relatively high; the organic carbon content is greater than 0.30 per cent and the nitrogen content is greater than 0.045 per cent. No quantitative plankton observations were made, but the fact that the transparency of water was lowest in the Gulf of Suez (Crossland, 1939) indicates that the subsurface layer must have been relatively richer in plankton than the other investigated regions. This explains why the sediments in this gulf are relatively richer in organic matter.

In contrast with the Gulf of Suez the organic matter content of sediments in the southern half of the Gulf of Aqaba is very low; the organic carbon content is 0.15 per cent or less and nitrogen content is smaller than 0.035 per cent. As to the cause of the poverty in organic matter of these sediments, it is suggested that it is due to two main factors. One of these factors is the scarcity of plankton, inferred from the high transparency of water (Crossland, 1939), which would result in a low supply of organic matter. The second factor is the rapid rate of decomposition of organic residues favored by the special environmental conditions in this region. Of these conditions the high oxygen content of water, which was greater than 60 per cent of saturation at any depth, the high temperature of the water, which was higher than 21.1°C. at any level, and the great depth of water are the most important.

The distribution of organic matter in sediments from the Red Sea proper presents a complicated picture. Thus, in the

southern approaches of the Gulf of Suez the organic matter content of sediments is relatively high at several places and comparable with that of the Gulf of Suez sediments. The nitrogen content is greater than 0.045 per cent in sediments from stations 19, 21A, 22C, 28A, 32F and 34L situated west of Shadwan Island, which lies at the southern end of the Gulf of Suez, and at stations 7 and 40 situated east and north of Shadwan Island respectively; the organic carbon content is greater than 0.30 per cent at a good number of these stations. The relative richness in organic matter of these sediments is possibly due to the transporting influence of the outflowing bottom current from the Gulf of Suez (Mohamed, 1940) which would carry the organic remains from the gulf and deposit them west and east of Shadwan Island as it slows down. However, at stations 14, 18, 20, 23C, 26 and 37 the organic matter content of sediments is rather low. It would seem that other factors such as the configuration of the bottom at these stations or the texture of sediments have a greater influence than that of the outflowing current from the Gulf of Suez. The influence of the configuration of the bottom on the organic matter content of sediments in this region is well illustrated by our findings at station 34 which lies over a submarine hill west of Shadwan Island. At the foot of the hill (station 34L) the organic carbon content is 0.30 per cent and the nitrogen content is 0.072 per cent, while at the other stations which lie on the slopes of the hill (stations 34A, 34E and 34H) the organic carbon content is less than 0.15 per cent and the nitrogen content is less than 0.035 per cent, i.e., less than half the amount found at the foot of the hill.

On the other hand, the amount of organic carbon found in sediments from the southern approaches of the Gulf of Aqaba is low and varies from 0.09 to 0.21 per cent, but the amount of nitrogen, which varies from 0.032 to 0.055 per cent, is somewhat high. The cause of this high nitrogen content is not very evident, although it is quite possible that some local conditions tend to render these sediments specially richer in nitrogenous constituents. Alternatively, it is probable that the environmental conditions in this region are such that the non-nitrogenous constituents of these sediments would decompose more readily than the nitrogenous constituents.

In the open region of the Red Sea proper the organic

matter content of sediments is generally low and varies within narrow limits; the organic carbon content ranges chiefly from 0.11 to 0.19 per cent and the nitrogen content from 0.016 to 0.031 per cent. However, the sample collected from station 83 has a somewhat higher content of organic carbon and nitrogen. It is interesting to note that upwelling of water, revealed by oceanographical observations, was taking place in the vicinity of this station. Consequently, supplies of nutrients brought to the surface would result in appreciable plankton production. Hence, the organic matter content of the bottom sample from this station was high.

From the foregoing it appears that the environmental conditions of deposition in the investigated region of the Red Sea proper, excepting the southern approaches of the Gulf of Suez, differ but little from those in the southern half of the Gulf of Aqaba and that poor organic production and rapid rate of decomposition are two factors dominant in determining the organic matter content of sediments in this region.

The carbon-nitrogen ratio.—The investigation of the carbon-nitrogen relation in marine sediments attracted the attention of many workers. Trask (1932) found that the average C:N ratio for 108 marine sediments collected from the Channey Islands area was 8.4, with variations from 5.3 to 13.5. Gripenberg (1934) found that the mean C:N ratio for 81 sediments from the Baltic Sea was 10. Wiseman and Bennett (1940) found that the average C:N ratio for 44 sediments from the Arabian Sea was 14.4, with variations from 4.9 to 34.2.

To investigate the carbon-nitrogen relation in the northern Red Sea sediments, the C:N ratio was calculated and the results are entered in table 2. The average C:N ratio is found to be 5.2, with variations from 2.0 to 8.2. It is evident that this ratio is lower than the corresponding ratio for sediments from other oceanic regions.

From the standpoint of the C:N ratio regional differences are found. Thus, the mean C:N ratio for the Gulf of Suez is 7.7, for the Red Sea proper is 4.6 and for the Gulf of Aqaba is 4.0. These differences would indicate that the conditions influencing the chemical make-up of organic matter deposited in each region are different. They further indicate that the Gulf of Suez sediments which are relatively richer in organic

matter have a higher mean C:N ratio than that of sediments from the other two regions which are poor in organic matter.

Granted that the origin of organic matter in marine sediments is due chiefly to the deposition of organic residues of plankton, it is pertinent to enquire how far the mean C:N ratio for the northern Red Sea sediments would agree with the proportion of these elements in the organic content of living plankton. The C:N ratio for mixed plankton as found by Fleming (1940) is 41:7.2 or 5.7:1 which is also in close agreement with the proportion of these elements in sea water. It is found that this ratio is in good agreement with the mean C:N ratio for the northern Red Sea sediments. It is even in perfect agreement with the mean C:N ratio for sediments procured from the stations situated in the open region of the Red Sea proper (stations 45, 67, 77, 78, 81B, 82A, 83 and 86); the mean C:N ratio for these sediments is also 5.7. In view of this agreement our results would seem to suggest that the C:N ratio in marine sediments might come to reflect the proportion of these elements in the organic content of living plankton and in sea water, at least as far as the open sea is concerned. Such a generalization would be of great interest.

SUMMARY

(1) The amount of organic carbon and nitrogen has been determined on bottom sediments from 38 stations in the northern Red Sea. It is found that the content of organic matter in these sediments is very low compared with that of other sediments.

(2) The distribution of organic matter in sediments from the various regions of the northern Red Sea has been discussed. It is found that sediments from the shallow Gulf of Suez are richer in organic matter than those from the Gulf of Aqaba or the Red Sea proper. The causes of these variations have been discussed.

(3) The mean C:N ratio of 38 sediments from the northern Red Sea has been found to be 5.2 which is lower than the corresponding ratio for other marine sediments. Regional variations in the C:N ratio are also found and it is suggested that they are due to different environmental conditions of deposition.

(4) The mean C:N ratio for bottom sediments from the northern Red Sea has been found to be in good accord with the proportion of these elements in mixed plankton.

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MOOREOCRINUS BOWSHERI, NEW SPECIES FROM THE CHESTER SERIES OF NORTHEASTERN OKLAHOMA

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ABSTRACT. *Mooreocrinus bowsheri*, new species, is described with a discussion of possible affinity with the rare eleutherozoic *Cryphiocrinus*.

INTRODUCTION

THE presence of a pseudo-Agassizocrinus fauna in the Chester formations of northeastern Oklahoma has been known to the writer for many years. It was not until Arthur Bowsher* discovered a specimen near Cedar Crest Lake that the true nature of the forms became apparent. Only the anterior side of a dorsal cup with some of the arms were exposed firmly imbedded in a hard, blue-gray limestone. Intensive preparation freed the posterior side of the dorsal cup and the lowermost ossicles of the arms. Affinity obviously was within the Cromyocrinidae rather than the Agassizocrinidae. Much information is needed before we will fully understand the genetic lines involved among forms at present assigned to the Cromyocrinidae. This species is closely similar to *Cryphiocrinus* Kirk but the writer has chosen to place it under *Mooreocrinus* Wright and Strimple because of the arm structure. General calyx outline and structure is that of *Cryphiocrinus* but in the basal area fundamental differences exist. A small stem is present, and a comparatively large, deep, basal invagination. There is no indication of a centrale; however, the IBB circlet is almost entirely covered by the proximal columnal so that definite observation is difficult.

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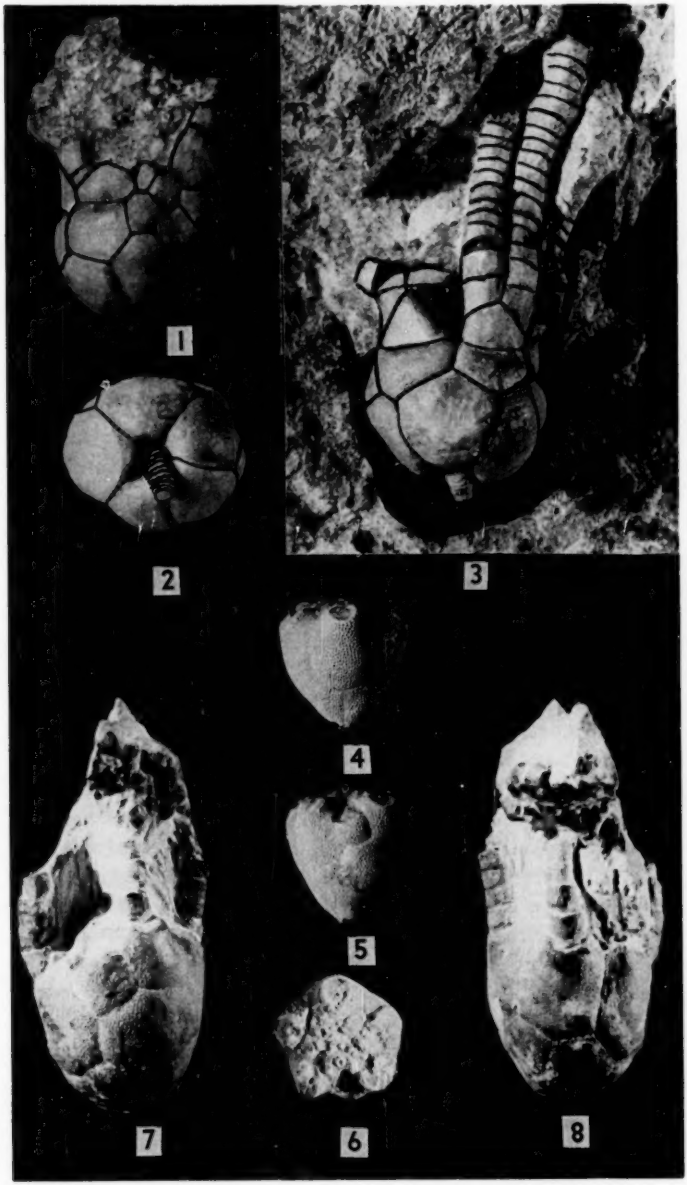
EXPLANATION OF PLATE 1

Mooreocrinus bowsheri, new species.

Figs. 1-3. Posterior, basal, and anterior views of holotype. Enlarged approximately two times natural size.

Hybocrinus crinerensis, new species.

Fig. 4, anterior view of paratype; Fig. 5, posterior view of paratype; Fig. 6, summit view of paratype; Fig. 7, posterior view of holotype; Fig. 8, anterior view of holotype. All figures natural photographs x 2¼.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Through loss of the stem, reduction of basal concavity and antrophy of IBB elements (followed by formation of a centrale) such a form as *Cryphiocrinus girtyi* Kirk could easily be derived. Kirk noted the presence of a minute stem cicatrix approximately .5 millimeters in diameter in the type of *C. rotundus* but considered the stem to be already detached at this stage. In an older paratype of the species a centrale covered the IBB. This is probably a correct assumption because similar occurrence has been noted among the agassizocrinids where the stem impression is present in young specimens, but entirely obliterated in older specimens.

It is recognized that normal evolutionary trends among these late inadunates is for a conical cup to become rounded, the base flat, with a deep basal invagination appearing in advanced stages. It is also understood we are involved in a highly specialized trend in this instance where a transition from statozoic to eleutherozoic habit is probably involved. Following such reasoning the basal area of *M. bowsheri* is only superficially advanced. Presence of a column is indicative of the primitive nature of the form in such a trend and is supported by the primitive three plate arrangement of the posterior interradius. In *C. girtyi* the RX is a modest element and has apparently migrated entirely out of the dorsal cup in *C. rotundus*.

Brief comparison with members of the Cromyocrinidae discloses the following: *Ureocrinus* Wright and Strimple, *Ulocrinus* Miller and Gurley, *Cromyocrinus* Trautschold, and *Tyrieocrinus* Wright all have broad, convex IBB circlets. *Mooreocrinus* Wright and Strimple and *Parulocrinus* Moore and Plummer normally have a slight basal concavity but retain strong, wide IBB circlets. *Ureocrinus*, *Cromyocrinus* and *Mooreocrinus* are the only allied genera having the primitive three plate plan to the posterior interradius, however, in *Ureocrinus* considerable variation is known to exist. *Ureocrinus* and *Cromyocrinus* have five uniserial arms and *Mooreocrinus* has ten uniserial arms. In *Ulocrinus* and *Parulocrinus* only *RA* and anal X are retained within the cup and in *Tyrieocrinus* a single anal plate is present.

The name *Mooreocrinus bowsheri*, new species, is proposed in slight acknowledgement of many contributions of Carboniferous crinoid specimens made by Arthur Bowsher.

DESCRIPTIONS OF SPECIES

MOOREOCRINUS, Wright and Strimple

Mooreocrinus bowsheri, new species

Plate 1, Figs. 1-3

Description.—Dorsal cup globose, constricted at the base of the arms and having a well defined, deep basal invagination. IBB circlet is almost entirely obscured by proximal columnal and apparently forms a flat surface at the bottom of the basal concavity. BB are large elements, proximal portions forming sides of basal invagination and curving sharply upward to form the erect sides of the dorsal cup. Post. B has seven facets, supporting small anal X above and large RA to the upper right. RA in turn supports a small RX above. RR are relatively small, five-sided plates and the uppermost surface curves inward so that meeting with PBrBr is not flush. Sutures between RR and BB are impressed. PBr are axillary and are slightly longer than wide. There are ten uniserial arms composed of moderately thick, rounded ossicles. There is no evidence of ornamentation though the surface of plates are rough appearing. Proximal columnals are thin, round, rather small and taper rapidly.

Measurements.—

	Holotype
Greatest width of cup	12.0 mm.
Height of cup	8.3 mm.
Width of proximal columnal	1.7 mm.

Remarks.—The pronounced basal invagination, presence of a small column and the somewhat elongate dorsal cup serve to readily distinguish *M. bowsheri* from other described species.

The species does not agree in some respects with the diagnostic characteristics of *Mooreocrinus* which form has a rather broad dorsal cup, with a shallow basal concavity and a wide IBB circlet. The arms of *Cryphiocrinus* are not known which prevents complete consideration of affinity with that genus.

Occurrence and horizon.—Unnamed formation (sometimes referred to as the Mayes formation), upper Chester series, Mississippian (lower Carboniferous); Cedar Crest Lake, Center

north line, Sec. 20, T19N., R20E., northeastern Oklahoma.

Holotype.—To be deposited in the U. S. National Museum.

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HYBOCRINUS CRINERENSIS, NEW SPECIES FROM THE ORDOVICIAN OF OKLAHOMA

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ABSTRACT. *Hybocrinus crinerensis*, new species from the Bromide formation of the Criner Hills near Ardmore, Oklahoma, provides some additional information and increased geologic and geographic range for this unique genus.

TWO magnificent specimens from the collection of Wm. T. Watkins of San Antonio, Texas, are presented as *Hybocrinus crinerensis*, new species. They were collected several years ago by Watkins at Rock Crossing, Criner Hills, southwest of Ardmore, Oklahoma, from the Bromide forma-

tion (Ordovician), and consist of a splendid dorsal cup with tegminal structure in excellent preservation, and a larger cup with arms attached which is the holotype.

HYBOCRINUS CRINERENSIS, new species

Plate 1, Figs. 4-8

Dorsal cup conical shaped, ratio of height to maximum breadth about 2:2.2. BB are large, spread rapidly from the small stem impression. RR are large elongate elements with the exception of r. post. R which is small and rests on the right shoulder of the large RA. Articular facets are small, constricted, and are devoid of articular ridges and grooves. Anal X is small, not elevated, and rests against the l. post. R, with support to the right by the left shoulder of RA and lateral side of r. post. R. There is an opening behind the anal X bounded by the posterior oral. No evidence of minute covering plates for the anal aperture has been found in either specimen, however, they might not be preserved.

There are five orals, the larger being posterior in position and attaining a greater height than approached by the others. A pronounced madreporite is present on post. O. Ambulacral grooves rest on the surface of the tegmen and converge to the center. Small covering plates are present but are mostly disturbed from their normal positions.

The five rami appear weak but seem to have attained considerable length. They are composed of rounded elements with sutures impressed. No pinnular structure has been observed.

Stem cicatrix is round, devoid of crenulations, and is pierced by a small pentalobate canal.

All plates are strongly porous, including the orals and rami.

Measurements.—

	Holotype	Paratype
Maximum height of dorsal cup	13.0 mm.	9.6 mm.
Maximum width of dorsal cup	12.2 mm.	8.9 mm.
Length of r. ant. B	11.9 mm.	4.2 mm.
Width of r. ant. B	4.8 mm.	3.5 mm.
Length of suture between BB	4.5 mm.	2.9 mm.
Length of ant. R (to proximal edge of articular facet)	5.5 mm.	5.0 mm.
Width of ant. R	5.8 mm.	5.5 mm.

Measurements.—continued

	Holotype	Paratype
Length of anal X	3.6 mm.	2.0 mm.
Length of RA	6.0 mm.	4.6 mm.
Width of RA	7.4 mm.	6.1 mm.
Diameter of stem impression	2.4 mm.	1.3 mm.
Width of arm articular facet	2.6 mm.	2.0 mm.
Length of arms (Maximum preserved)	16.3 mm.	—

Remarks.—*H. crinerensis* is close to the genotype species. *H. conicus* Billings, differing mainly in the following respects: more obliquely placed anal X; a broader, fuller dorsal cup; lower placement of anal opening; less protrusion of r. post. R. The right posterior portion of *H. conicus* is very distended, causing an asymmetrical appearance to the cup, particularly when viewed from the summit. Although the r. post. R of *H. crinerensis* has a high position in the cup, and there is a mild protrusion, no decided appearance of irregularity is attained.

A peculiar twist to the dorsal cup in the basal area is of conjectural value. When the cup is viewed from the posterior side, the basal elements twist from left to right and slightly forward. This same development is found in *H. conicus* and indicates a directional leaning. Possibly the lack of pinnular appendages forced the forms to adopt a permanent leaning attitude into the current to augment their food gathering powers. The writer has noticed this slight basal twist in a later (Pennsylvanian) non-pinnular form, *Allagecrinus*, wherein the column is normally curved in the proximal region and sporadic arm development is prevalent.

Occurrence and horizon.—Bromide formation, Ordovician; Rock Crossing, Criner Hills, southwest of Ardmore, Oklahoma.

Types.—To be deposited in the U. S. National Museum.

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Bartlesville, Oklahoma

TYPES AND HYPODIGMS

NORMAN D. NEWELL

ABSTRACT. As pointed out by Simpson, traditional attitudes toward the functions of type specimens, particularly in paleontology, seriously impede accumulation of knowledge about natural groups of fossil animals and plants. Until collections of specimens are viewed as co-equal members of a statistical sample, taxonomic species and subspecies will not closely correspond to natural groups. Simpson has introduced the term "hypodigm" for the statistical sample of a population. This sample can, and should gradually expand, and from time to time should be revised. The purpose of the present discussion is to call attention to certain limitations and principles that should govern the use of the hypodigm concept. Certain categories of types which would be abandoned by Simpson have, I believe, real curatorial value which argues for their retention.

INTRODUCTION

ESTABLISHED practice in the taxonomy of fossil organisms involves the use of type specimens to a much greater extent than with living species. Probably only a small proportion of living species are based on extant type specimens. The majority of kinds of animals and plants are too perishable to permit the use of types. Also, the teeming abundance of authentic duplicates in most cases has made the use of a single set of reference standards, such as a holotype or type collection, unnecessary. The situation is different with fossils. Well preserved *unquestionably authentic* representatives of a species in addition to the original type collection hardly ever are generally available. For this reason the original type series on which thousands of fossil species are based are unique in that they alone possess one or both of the following attributes: 1) In some examples the type specimens are the only well-preserved specimens known; 2) because of vague records, or inaccessibility of the exact stratum from which the original types were obtained, they commonly represent the only obtainable specimens definitely referable to a given time level. Hence, all additional specimens almost certainly belong to populations and races younger or older than those from which the types were collected.

Many paleontologists confronted by variation in time and space induced in organisms by evolution and ecological modifications generally have been impressed by the difficulty in

assigning limits to a given species. Lacking statistical data on the variability of practically all paleontological species, they have in practice, although perhaps unconsciously, assumed that in the last analysis the only "authentic" representatives are the holotype and specimens similar to it from the same locality and horizon (topotypes). The original types then, together with any additional conspecific specimens from the type horizon and locality, constitute a final court of appeal for purposes of comparison. According to this viewpoint the original types and topotypes, beyond any reasonable doubt, belong to a single or at least to very closely related populations, and they alone are incontrovertible. Comparison of other suites of specimens with these is subject to individual interpretation.

This method was necessary and useful before quantitative methods were applied to paleontological problems. Statistical analysis is still not widely employed in paleontological studies. We may be sure, however, that the ultimate requirements of refined stratigraphical and paleobiological studies call for recognition of persistant, obscure differences and real "identities" in separate fossil populations regularly demonstrable *only* by quantitative methods. These tend to reduce confusion arising from the play of individual judgment and experience, and will permit for the first time in the history of the science, cumulative increase in significant knowledge of species and subspecies. In the past, descriptions and revisions that do not include the original types, or topotypes of a species, have not been generally regarded as authoritative, hence, knowledge of these lower taxonomic categories under this system scarcely could expand.

In an inspired resumé of the type problem, George Gaylord Simpson recently has fired the first round in an attack on the traditional views toward types held by most paleontologists (Simpson, 1940). Like the majority of thoughtful taxonomists, he deplores the absurd extremes reached by existing terminologies of type specimens. By his tabulation these include more than 51 separate kinds of "types." According to the most elaborate schemes practically all collected specimens would belong to one or more categories of types.

The purpose of the present paper is to explore some of Simpson's proposals for a greatly simplified scheme that will

harmonize modern taxonomic theory with paleontological practice.

FUNCTIONS OF TYPES

Type specimens in ordinary paleontological practice have served as 1) bases for definitions, 2) as standards for comparison, and 3) as fixed biological points in variable populations to which binomial names are attached. According to Simpson, "the modern conception of taxonomy as involving the inference of population characters from samples makes it impossible for the same items properly to serve all three of these purposes. . . . The newer theory of taxonomy as a system of group concepts based on inferences about populations from samples . . . is decisively incompatible with this use of 'types'." (*Op. cit.*, p. 413.)

The three-fold function of types still generally in use in paleontology is a natural heritage of the "type" concept in neontology, only recently generally abandoned by students of living organisms. It is inevitable that the paleontologists, following the lead of zoölogists and botanists, will eventually learn to view their collections of specimens as *samples of populations*. As such, collections cannot individually define the characters of species. They can serve only as useful and valid measures of the particular populations to which they belong, provided, of course, that they are properly analyzed.

Species and subspecies are real in nature. They are groups of individuals that are closely related and that vary between limits, however vague and arbitrary.[1] Our concepts of species and subspecies are, of course, subjective and probably never can be more than rough approximations of the true species in nature. Nevertheless, one of the main objectives, perhaps the chief goal of the taxonomist, is to learn as much as possible about the subspecies or species, and every effort should be made to accumulate accurate and adequate information about their characters. Most forms are far more variable than commonly is recognized. An elementary statistical analysis generally is needed for a valid quantitative statement

[1] For example, it is probable that evolution in time is generally or invariably a continuous process. Limits of species are drawn at convenient gaps in the fossil record. There is no reason to believe, however, that these gaps are universal, and annectent forms found after species boundaries are arbitrarily set must be dealt with just as arbitrarily.

of that variability. Likewise, two subspecies of a given species may be clearly and regularly separable only by means of appropriate quantitative methods.

THE HYPODIGM

Traditionally, the original or type collection is the basis for defining and limiting species. Individual variants which fall well outside the artificial limits set by the type specimens necessarily fall in some other category (species, subspecies, or "variety"). Under these circumstances the types *are* the taxonomic species. Clearly, species established on these premises have very little in common with species in nature. Furthermore, there is no provision in this method for accumulating new knowledge about natural species.

Simpson (1940) has shown by means of his *hypodigm* concept, how collections of specimens can provide significant data on natural species and this knowledge can be cumulative as new specimens are acquired. The hypodigm is the *population sample* by which characters of the entire population are assessed. The composition of the hypodigm changes as new specimens are added to it, and as original types or other specimens are removed as required by revision. At the time of description of a species (or subspecies) the hypodigm consists only of the type lot.[2] Subsequent critical studies of the species based on additional specimens should add to knowledge of the species *by increasing the size of the hypodigm.* The hypodigm then is really a statistical sample. As this sample increases in size by acquisition of new collections (by various workers at various times) the appraisal of the whole population, if *uniformly based on quantitative methods*, gradually approaches the facts in nature. The taxonomic species

[2] It appears to me that the type lot includes *all* of the specimens referred to the new species, subspecies, or "variety" by the describer in the original publication. If no holotype is selected all of the specimens are syntypes (cotypes). If a holotype is designated all of the remaining specimens are paratypes. A limited survey of usage, however, shows that some paleontologists adhere to the view that paratypes or syntypes must also be separately designated. According to this view specimens unspecified in the original publication are not types at all. I know of no authority for this, and it seems to me basically unsound. Even those specimens not referred to in the description and not critically studied enter into the author's impression of his species and influence the result. Hence, they form part of the type lot.

then will be objective and will resemble natural species composed of one or several whole populations.

The possibilities inherit in this concept are overwhelming in implication, and should lead to complete revision in paleontological thought and procedure.

FOSSIL POPULATIONS

There are practical difficulties and limitations in use of the hypodigm which I believe require careful consideration. The function of the hypodigm is to enable us to learn as much about natural populations as possible through the use of samples from those respective populations. Unfortunately, it is not at all clear how a fossil population may be defined or recognized.

A brief survey of neontological literature indicates that a population, amongst living organisms, is an effectively interbreeding aggregate which forms a gene pool more or less apart from other closely related aggregates. Through isolation, which may be of several degrees and kinds, a population may acquire distinctive gene properties. Under these conditions a subspecies may arise, being co-extensive with one or more populations. Further evolution may produce separate species, which generally comprise a large, but variable number of populations. In space, populations tend to be segregated geographically, or ecologically. In time, however, they certainly must occupy points in a continuous process of organic change. For this reason the vertical boundaries of fossil populations are vague in the extreme. Elsewhere (Newell, 1947, p. 163) I have tried to define (living and fossil) populations in time. "We may speak of past or future populations, or of successive populations. Thus, a population does not have time duration. A subspecies certainly does have time duration (because its vertical limits may be arbitrarily fixed), hence, a subspecies is composed of a succession of gradually changing populations."

It will be seen that only under closely limiting conditions can a hypodigm of fossils be restricted to specimens from a single population. Approximate contemporaneity in a collection of fossils cannot always be proved, and it is probable that most accumulations of fossil skeletons represent an appreciable span of time. At best then all of the specimens in

a hypodigm clearly should be closely related, and should exhibit approximately the random variation characteristic of single or very closely related populations. If the hypodigm is not critically assembled, significant errors through contamination will enter into the cumulative results. By definition "every specimen definitely referred (in publication) to a species is, or has been, part of its hypodigm" (Simpson, *Op. cit.*, p. 419). That is, every specimen studied and definitely referred by an author to a species is part of his statistical sample for that species, *i. e.*, is part of *his* hypodigm. Other authors, using additional material, will of course, have somewhat different hypodigms. Successive descriptions will progressively lead to refinement of elimination of spurious data, and there will be an overall tendency for the hypodigms to become more comprehensive and taxonomic boundaries will be extended with discovery of new specimens. In this way knowledge of variation in natural groups is cumulative rather than static as in the "type" method of comparisons with fixed standards.

Homogeneity of the sample is, of course, one of the primary objectives of the hypodigm. It is not implied that a fossil species or subspecies should be co-extensive with single populations. The hypodigms, even of living forms, include materials that are not strictly contemporaneous, and only approximate contemporaneity can usually be claimed for any two fossil individuals. A hypodigm is sufficiently homogeneous for taxonomic purposes if it displays approximately the random variation of the normal curve of frequency distribution. At least approximate contemporaneity of the individuals forming the hypodigm lends additional valuable evidence that the sample is not contaminated with homeomorphs or examples of parallelism. In most cases, an effort should be made to limit hypodigms to narrow stratigraphic units, or to single bedding planes in order to recognize the smallest stages in the evolution of a group. This may not be adequate or feasible in all cases. In the more slowly evolving animal stocks, species commonly are reported to range through an entire series or system. Careful work on such forms may show that collections from several horizons may profitably be joined into a single hypodigm which better reveals the group characters than do collections from a single horizon.

QUALIFICATIONS OF HYPODIGM SPECIMENS

One characteristic of paleontological materials in general is that they tend to be fragmentary or relatively rare. There are many exceptions, of course, but commonly it is impossible to assemble a large number of individuals from *a single horizon and locality*. Hence, a majority of fossil species were founded on "mixed samples," that is hypodigms which contain specimens certainly not of a single population. Less commonly, the original hypodigm contains representatives of two or more species, as every reviser well knows. This hazard should be recognized and noted, but probably it is not in itself adequate grounds for eliminating from consideration instructive isolated specimens if the original hypodigm is very small. It should be self evident that obscure but real and persistent morphological differences between two subspecies sometimes are recognizable only by means of adequate quantitative analysis. Hence, isolated individuals in such circumstances cannot, with certainty, be ascribed to the proper subspecies.

In consequence, any type collection which is composed of specimens from several horizons and localities is likely to lead to incorrect inferences, since it may not represent any natural group. In such an original hypodigm, I believe, contrary to Simpson's conclusion, that the members of the hypodigm should not be of equal rank. For the needs of revisers they should be clearly differentiated. One of the most convenient methods, that is already in general use, is the application of special terms to the most significant categories of "type" specimens.

TYPE TERMINOLOGY

For new work and review Simpson proposes abandonment of all type designations except the following: (Simpson, *Op. cit.*, p. 424);

Hypodigm—the statistical sample, distinguished from types and discarding the idea of types as bases for species and for comparisons.

Type—the single name-bearing and anchoring specimen. In review and revision only Simpson favors retention of the following:

Syntype—one of two or more specimens to which a single name was equally attached in the original publication.

Lectotype—a syntype subsequently selected to be sole name-bearer.

Neotype—a specimen substituted as name-bearer for one not now assignable to a definite hypodigm.

These are basic categories, but they do not satisfy all needs, in my opinion. In general it seems to me that a very useful function is fulfilled by a few additional kinds of types.

In the original type lot, or hypodigm, it is desirable to stress the circumstantial evidence that indicates which specimens possibly belong to the same subspecies or population, and which ones probably do not. It would seem sound practice to segregate the name-bearer, the holotype, or type as it is simply called by Simpson, together with all of the topotypes. This fraction of the hypodigm is likely to remain as a permanent part of the hypodigm; other specimens may be removed by a subsequent reviser. I agree fully with Simpson that paratypes (unless they also are topotypes) should be accorded no more significance than any other representative of the group in evaluating the species. In my opinion paratypes do play an important rôle. The merit in applying the term paratype to supplementary specimens in the original hypodigm is that the designation carries some prestige and is some insurance that the hypodigm will not be broken up for exchange purposes. It also stresses the published documentary value of the specimens. Implicit in the hypodigm concept is the idea that a large collection will tell more about a species or subspecies than will a small collection, and that a single type specimen will reveal very little about the natural group to which it belongs. For this reason it is urgent that large collections of a species be kept intact. I would term paratypes that come from *precisely* the same horizon and locality as the holotype topoparatypes, to distinguish them from the much less useful stray paratypes. It is clearly understood that the holotype and paratypes do not reveal any more information than subsequently described specimens of the group. Subsequently described additional specimens, in my opinion, are best segregated and designated in order to show that they also are part of a hypodigm. They are the hypotypes. To leave these published specimens without special designation en-

dangers their future preservation. The term diplotype[3] for holotypes and lectotypes of genotype species is meritorious, it appears to me. As a name-bearer this category is pre-eminent, and a distinctive term as a safeguard is of great value for curatorial purposes.

In summary, I would recommend expansion of Simpson's list as follows:

Hypodigm
Diplotype
Holotype
Topotype
Paratype
Topoparatype
Hypotype
Syntype
Lectotype
Neotype

[3] A few writers have consistently misused genoholotype for Knight's "diplotype." Genoholotype is the *type species*, it cannot apply to a single specimen.

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The American Museum of Natural History
and Columbia University

REVIEWS

Outlines of Physical Chemistry; by FARRINGTON DANIELS. Pp. viii, 713, 164 figs. New York, 1948 (John Wiley and Sons, $5.00). This book is essentially a new edition of the text formerly published under the joint authorship of Getman and Daniels. In order to provide a more logical discussion of the subject matter, the chapter on thermodynamics has been moved into an earlier section of the book where it now follows the treatment of heat capacity and thermochemistry. The material from the chapter on thermodynamic applications has been incorporated in appropriate sections throughout the text. The problems have been revised and their number increased.

As was the case for earlier editions, the aim of this book is to provide material for a first-year course in physical chemistry. Fortunately it is not directed at any particular class of students. In view of the broad coverage, the discussion of some topics (notably imperfect gases, specific heat, and entropy) is necessarily restricted. However, the clearly written, authoritative treatment of solutions and their electrical properties, equilibrium phenomena, chemical kinetics, photochemistry, and colloids, furnishes once again an excellent basis for the conduct of an introductory course. Considering the imperative limitation on length, these sections are surprisingly comprehensive.

In this new edition some of the newer topics in physical chemistry, such as radiochemistry and chromatography are treated in somewhat greater detail than before, as are the older fields of spectroscopy and photochemistry. In view of the tremendous commercial and scientific interest in polymers, the consideration of these materials is unexpectedly brief.

Professor Daniels' emphasis on the practical is indicated by the inclusion of a wide variety of problems. More than one hundred solved, illustrative examples have been inserted to supplement the text. Unfortunately, only a few of these solved problems are of the "thought provoking" type with which the exercise sets are liberally furnished.

It has been the author's expressed purpose to "raise the level of the presentation to keep pace with the improved preparation with which students are starting the study of physical chemistry." The relegation of such topics as the determination of activity coefficients to the appendix, which had already included such things as the discussion of partial differentiation, would indicate that perhaps this preparation has been leveling off.

Typographical errors, such as the omission of superscripts in the section on chemical equilibria, are infrequent and trivial. In

appearance and content, this is a better book than the older editions, which have been so justly popular with student and instructor alike.

P. A. LYONS

Précis des Découvertes Somiologiques ou Zoologiques et Botaniques; by C. S. Rafinesque. Pp. 55. Palermo, Sicily, 1814 (Lithoprint reproduction, New York, 1948, Peter Smith, 321 Fifth Avenue, N. Y., $4.00).—The original edition of this early work by Rafinesque is one of the rarities of biological literature. Its reprinting makes it available widely to the many plant and animal taxonomists who are forced to consider it in their inescapable nomenclatural labors and the small printing of 350 copies should be exhausted as soon as its announcement is circulated widely.

In a prior work Rafinesque had outlined his plan for a new science "Somiologie, qui signifie la Science des Corps vivans, pour désigner collectivement la Botanique et la Zoologie unies entre'elles et régies par des loix pareilles." He designated the plant and animal kingdoms as the "Empire somiologique," in contrast to the "Empire minéralogique." Plants and animals are each divided into ten classes. The prefatory remarks provide amusing reading, but the importance of this little volume is in the systematic portion in which are described 50 new genera and 190 new species of animals and plants. Most of the material is from Sicily, but 6 new genera of plants and 45 new species of fishes and plants are from eastern North America. The names of scores of other new species are mentioned, although their descriptions are deferred until later works. As Professor E. D. Merrill states in the foreword to the lithoprinted copy, Rafinesque's work is characterized by "inconsequential original descriptions." However, it must be admitted that most of the descriptions in this volume are as significant as those of Linnaeus and even more so than those of many of the most famous later authors of the Eighteenth Century. The modern correlation of the names has not been attempted in many cases, since this work is surely unknown to most zoologists. The ten species of insects named will be almost impossible to correlate with known species. It seems equally certain that in most other groups these Rafinesquian names must become *nomina nuda*.

CHARLES L. REMINGTON

College Physics; by HENRY A. PERKINS. Third Ed. Pp. x, 786. New York, 1948 (Prentice-Hall Inc., $6.65). This new edition of a well-known and popular physics text will be welcomed by its many users. The alterations consist principally in the addition of new material, such as m.k.s. units, nuclear energy, cosmic radiation and radar. Several of the formal demonstrations have been simplified and made clearer.

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VOL. 247 No. 2, 1949

CONTENTS

THE FLOOR OF THE SHENANDOAH VALLEY ..... *Philip B. King* 73

LATE PLEISTOCENE AND RECENT CHANGES OF SEA LEVEL ALONG THE COAST OF SANTA BARBARA COUNTY, CALIFORNIA ..... *J. E. Upson* 94

THE DISTRIBUTION OF ORGANIC MATTER IN SEDIMENTS FROM THE NORTHERN RED SEA ..... *A. F. Mohamed* 116

Mooreocrinus Bowsheri, NEW SPECIES FROM THE CHESTER SERIES OF NORTHEASTERN OKLAHOMA *Harrell L. Strimple* 128

Hybocrinus Crinerensis, NEW SPECIES FROM THE ORDOVICIAN OF OKLAHOMA *Harrell L. Strimple and William T. Watkins* 131

TYPES AND HYPODIGMS ..... *Norman D. Newell* 134

REVIEWS

Outlines of Physical Chemistry; by FARRINGTON DANIELS ..... *P. A. Lyons* 143

Précis des Découvertes Somiologiques ou Zoologiques et Botaniques; by C. S. RAFINESQUE ..... *Charles L. Remington* 144

College Physics; by HENRY A. PERKINS ..... *C. G. Montgomery* 144

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